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Hewlett-Packard Company (A)

Mechanical Design of Coaxial Microwave Connectors

As of mid 1963, engineers at the Hewlett-Packard Company are considering what action, if any, they should take regarding standard connectors for coaxial conductors used with the company's line of microwave instruments. A large number of different types of coaxial connectors have come into use and have been classified as standard by various governmental agencies and industry groups. Some standard types of connectors are illustrated in Exhibit A1.

Existing standard coaxial connectors are considered inadequate because they tend to cause serious reflections of power at high frequencies. Existing standard connectors are also considered inconvenient to use because they are not sexless. Each connector is either male or female, and no two of the same sex can be joined without interposition of an adaptor. To join two males or two females it is necessary to locate the correct adaptor from among the many that must be kept on hand for interconnecting the various types of plugs, and then to fasten the adaptor to one of the connectors before the other connector can be joined. Adaptors also tend to cause power losses and reflections at high frequencies, as do standard connectors.

This case material was prepared in the Design Division, Department of Mechanical Engineering, Stanford University, by Karl H. Vesper, with support of the National Science Foundation. Vital assistance from Anthony Badger, James Ferrell, Nicholas Kuhn, and Robert Prickett of the Hewlett-Packard Company and from Peter Z. Bulkeley and Donald D. Winslow of Stanford is gratefully acknowledged.
*Revised in July 1968 by Richard C. Bourne.

Electrical engineers know ways to improve the electrical characteristics of existing connectors, and two companies are making connectors which not only incorporate some such electrical improvements, but also are sexless, so that any two can be joined without an adaptor. Each of these companies has urged that its improved connector be adopted by the industry as standard. However, neither improved connector has yet been so accepted, and neither is yet being widely used. Both of these improved connectors are expensive, being priced about ten times as high as the older standard connectors. These improved connectors are available only in the large line sizes and not in the smaller 7 mm. line size, which is the size used most extensively at Hewlett-Packard.

Hewlett-Packard

Products of the Hewlett-Packard Company can broadly be grouped into two general categories: (1) Electronic Instruments, including oscilloscopes, oscillators, voltmeters, ammeters, power supplies, electronic counters, etc., and (2) Microwave Equipment. The company's microwave products can also be divided into two categories: (1) Test Instruments, such as various meters for measuring microwave characteristics, signal generators and amplifiers, and (2) Microwave Circuit Elements, such as waveguides, directional couplers, etc. Prices of most Hewlett-Packard products are over a hundred dollars, and many of them sell for several thousand dollars each, but the company also makes and sells some small items for less than ten dollars each. These products of the company are sold throughout the world through a force of several hundred salesmen and independent manufacturers' representatives.

The main plant and home office of Hewlett-Packard is in Palo Alto, California. The company has other plants in the United States, and in England, Japan, and Germany. In total, the company employs over 6,000 people and manufactures over 1,000 different types of test instruments. In the Microwave Division there are about 50 engineers, most of whom are electrical engineers and a few of whom are mechanical engineers. Each mechanical engineer typically has his own desk, workbench, and drafting table on which he makes his own layout drawings.

Some of the engineers familiar with the shortcomings of existing standard coaxial connectors have suggested that Hewlett-Packard should undertake to develop a better one. They are aware that there is no shortage of projects needing engineers' time. They estimate, however, that the requirements for better connectors might range as high as 10,000 units per year within the company alone, and that outside the company the market could run into hundreds of thousands per year if the new connector were sufficiently better than those presently in use.

Microwaves and Their Uses

Microwaves are used in radar, communication (in space for communicating with satellites and rockets, and on earth for communication relay links between cities to carry television, telegraph, telephone and radio signals), radio astronomy, and spectroscopy.

Two properties of microwaves make them particularly useful. One is that they contain a tremendously wide range of useable frequencies for communication, because their frequency range is over one hundred thousand megacycles in contrast to the normal radio band which spans about one megacycle. The other is that they are highly directive and, like light, can be focused, beamed, and aimed at targets.

Optical techniques can be used in microwave applications particularly at higher frequencies. For instance, microwaves reflect from a conducting plane exactly as light waves reflect from a metallic mirror, with equal angles of incidence and reflection, and with unchanged amplitude. Diffraction of microwaves is also analogous to that of light waves. Microwave properties analogous to light make it possible to channel the waves with reflectors, to focus them with lenses, and to beam them with antennas. Departures from ideal light ray behavior result when microwaves, and for that matter radio and other longer electromagnetic waves, interact with objects smaller than their wavelengths.

Examples of microwave communication systems can sometimes be seen from the highways. Telephone communication links, consisting of horns shaped somewhat like the speakers of early phonographs may be seen on

mountain tops or high towers roughly 30 miles apart. Usually there will be a receiving antenna, an amplifier unit which adds power to the signal, and a sending antenna, with its back to that of the receiving antenna, which sends the signal onto the next station. Through one of these stations, as many as 10,000 phone conversations may be passing simultaneously.

Future trends in microwave technology seem to point toward working with higher powers, higher frequencies, and higher efficiencies. Radar and communication applications call for ever greater range and finer resolution of information, while for use in satellites and other space gear, future objectives include lighter weight, higher efficiency, and greater compactness.

Working with Microwaves

Microwaves are handled with electronic equipment, much of which looks similar to circuitry used for dealing with electromagnetic energy at lower frequencies. However, there are some unusual aspects to the appearance of microwave equipment. For instance, among the circuit elements there can be observed metal pipes, usually rectangular in cross section, called "waveguides" which are not used in lower frequency circuits. A waveguide can be considered analogous to a hallway of mirrors down which the wave proceeds in a zig-zag path, reflecting along back and forth between opposite walls. The path can be predicted in optical terms. Such a hallway must have certain minimum cross-sectional dimensions to propagate waves of a given frequency (color, in the optical portion of the spectrum) and these minimum dimensions increase with decreasing frequency.

Many electrical and electronic rules and techniques apply to microwaves, just as some optical methods do. But again in dealing with microwaves, some departures from convention are required. For instance, the fact that microwaves might be shorter in wavelength than the lengths of the circuits through which they flow can cause circuit parameters to vary with position. Two circuits which would be equivalent to one another at lower frequencies may not behave at all alike at microwave frequencies.

Reflection occurs in microwave transmission whenever there is an impedance discontinuity in the transmission system. Such discontinuities can be caused by any abrupt variation in the transmission path, such as either a sharp change in physical dimensions or a change in the electrical characteristics of the conductor. Therefore, it is preferable to make contours of the transmission path smooth, and if any changes in cross-section perpendicular to the flow are necessary, to make them gradually.

Transmission of microwaves can be accomplished in several ways. The waves can be beamed through atmosphere or space from antennas, and they can be channeled through several types of conductive devices. One such conductive device is the waveguide mentioned above, while others include "striplines" and different types of "coaxial lines". Striplines usually consist of flat sheets of dielectric material with thin flat metal conductors on the surface. Coaxial lines consist of two concentric circular conductors, an outer conductor and a center conductor. The conductors carry the electrical currents, while electromagnetic waves flow in the dielectric material (which can be air) separating them. The shape of the dielectric path is critically important in determining conductive characteristics. Illustrative pictures of waveguides, striplines, and coaxial lines appear in Exhibit A1. Normally no outer insulation is required on these conductors, because the outer conductor is usually grounded.

Striplines and coaxial lines by their natures cause high power losses at frequencies above roughly 12 to 15 gigacycles, and therefore it is necessary to use waveguides, which have very low losses, at high frequencies. For low frequencies, all the way down to direct current, however, coaxial lines and striplines do not cause high losses and are preferable to waveguides because they are easier to make and less bulky in use. As with waveguides, higher frequencies require smaller cross sections perpendicular to flow in coaxial conductors. Striplines and coaxial lines are roughly comparable to each other in performance, and the main reason for choosing one over the other is convenience of manufacture. Striplines are made by photoetching the desired longitudinal cross sectional shape of the conductor onto copper which is plated to a thickness of 1/3 to 3 mils on a plastic dielectric sheet perhaps

1/16 inch thick. With this photoetching process it is easier to make irregularly shaped conductive sections than it is with coaxial lines. The dielectric with its imprinted circuit is held in a frame, usually of aluminum, which may also serve as an outer conductor. A single stripline might weigh as much as two or three pounds.

Coaxial lines are made in the form of rigid conductors and also as flexible cables. The rigid line consists of a metal tube as outer conductor in which a metal rod as center conductor is held concentrically by plastic spacers. For precision microwave work at higher frequencies, tolerances on diameters of the metal conductors are held as close as 0.0002 inches and concentricity of the conductors to 0.001 inches. Where less precision is required, flexible coaxial cables made out of wire with insulation separating the inner and outer conductors may be used. The outer conductor in flexible coaxial lines is woven, while the inner conductor may be solid or also may be woven. Such flexible conductors are generally easier to use than either waveguides or solid lines, but their dimensions and concentricities are also less precise. Manufacturers of flexible lines have been working to make flexible conductors more precise by holding closer tolerances in manufacture. They have also been designing flexible cables which retain concentricity better by the use of dielectrics with higher resistance to cold flow and by braiding inner conductors to lower their bending stresses.

Junctions of microwave conductors are usually made either with bolted flanges or else with coaxial connectors. Waveguides are made with flanged ends having bolt holes. To connect the guides, these ends are simply tied together with nuts and screws. Coaxial lines and striplines may also fasten with flanges, but more often they are joined by coaxial connectors. Smooth fairing of the internal dimensions of the lines is important to minimize reflection. Since the path of the waves is between the conductors, the outside shape of the inner conductor and the inside shape of the outer conductor must be smooth along the flow. The inside shape of the inner conductor and outside shape of the outer are less important in terms of electrical performance. The outside of the connectors is generally not insulated.

Use of Connectors with Microwave Instruments

In work with Microwaves at Hewlett-Packard it is common for test set-ups to require quite a few non-permanent connections between various pieces of apparatus. It is not unusual for a given test circuit to require a dozen or more such connections, as can be seen from the illustrative experimental setups depicted in Exhibit A2. With each experimental setup shown in the Exhibit it will be noted that there are included in the picture a number of alternative pieces of gear which could be substituted in the circuitry.

With waveguides, changing connections requires unscrewing all the screws and nuts holding the flanges together and refastening other flanges. With standard coaxial connectors, it requires unscrewing the caps, pulling the connectors apart, pushing another pair of connectors together, and screwing the caps tight again. It is important that the connectors be tightly fastened for them to conduct as well as possible.

If two male or two female coaxial connectors are to be joined, there is the additional chore of locating an adaptor from among the many on hand for different sexes and different types of connectors, and fastening both sides tight to the adaptor. Finger protectors have been tried by one man to lessen skin abrasion, but they have not proven very helpful. "You just have to develop callouses", another engineer comments, "especially when you get into testing where you may have to make something like 1200 connections in ten hours."

Standard Coaxial Connectors

A wide variety of coaxial connectors have come into use, most of them having been devised in the radar development programs of World War II. Electronic specifications for these original connectors were not highly exacting because early knowledge and techniques of microwave work did not require them to be. Mechanical standards were set rather loosely for the same reason and also because of pressure during World War II to get work out as fast as possible. With time, the loose standards have come into wider and wider use, making it progressively more difficult to change them.

Also with time, the number of different sizes and types of connectors has grown, as new connectors have been developed for special applications and subsequently become widely used and hence standardized. For joining these different sizes and types together, adaptors must be used, so the proliferation of connectors has been matched by a proliferation of adaptors. Adaptors are also needed for joining connectors of the same sex, as was mentioned above, which has further multiplied the number of fittings required. An attempted remedy to the mating difficulty has been general agreement that connectors on instruments would all be female and connectors on cables would be male. But sometimes it is desirable to join two instruments directly in order to minimize losses or achieve certain line dimensions, and at other times it is desirable to extend a cable by joining it to another cable. Unfortunately, adaptors often introduce additional impedance discontinuities and cause power losses.

The most widely used coaxial connectors at Hewlett-Packard are the "Type N" standard connectors. The connectors, which are manufactured by a number of companies, are illustrated in the drawings and pictures of Exhibit A3. Type N connectors are of the male-female type, joining by a knurled cap which requires three to four revolutions for tightening. They cost from forty cents to four dollars each, depending upon the tolerances and finish required. Hewlett-Packard, which uses roughly 2,000 such connectors on its new instruments per year, prefers to have its connectors made to tighter specifications than standard. By so doing, it is possible to improve upon the electrical performance, although by its very design the connector still retains adverse electrical characteristics, and, of course, there is no way of knowing that the connectors with which customers will hook up the Hewlett-Packard instruments will be any better than standard.

Deficiencies in design which are considered to produce unfavorable electrical characteristics in the Type N plugs include the following:

1. Both male and female Type N connectors have cylindrical sections longitudinally slotted to let them spread and spring tight around each other when they are pushed together. Slight variations in

the slots or slight variations in radial thicknesses of the cylindrical sections can push the union off center, producing an abrupt change in the conductive path and thereby producing reflective power losses. Even the same two connectors can vary in conductive characteristics, depending on the orientation in which they are joined.

2. The slots themselves also produce a step change in both the outer shape of the inner conductor and the inner shape of the outer conductor which set up reflections.

3. Because the male and female conductors overlap it is not possible to define a reference plane at which the connectors join. For microwave measurements it is sometimes desirable to be able to short a line at a known point.

4. It is not possible to know which parts will butt together inside the connector, because there is more than one point at which the butting might occur, longitudinal tolerances are loose, and none of the butting surfaces can "give" in order to let other butting surfaces come together. Whichever conductor does not butt tightly leaves a sharp change in conductive path which causes reflections.

5. Overlapping and rubbing of the mating parts causes wear inside the connectors, which in time can change their shape and electrical properties. The chafing also produces chips and flakes which are difficult to remove from receptacle portions of the connectors and which can change electrical properties.

Existing Sexless Connectors

Two sexless coaxial connectors are commercially available in the larger line sizes. These are the "Dezifix" manufactured by the Rhode and Schwarz Company of West Germany, which has been available for several years, and the "Type 900", manufactured by the General Radio Company of West Concord, Massachusetts, which has been introduced within recent months. Both are currently

available only in line sizes larger than 7 millimeters, although Rhode and Schwarz has developed a model for 7 millimeter line which reportedly is soon to be put on sale. Engineers at Hewlett-Packard have some pictures and drawings of these connectors although they have not yet used either the Dezifix or the Type 900. In Exhibit A4 are pictures of the Dezifix Type B, which is larger than 7 millimeters and is available. Exhibit A5 shows a drawing of the Dezifix Type A, which is for 7 millimeter line, but not yet available commercially. The Type A is believed to be simply a scaled down version of the Type B, but with the addition of a centering device using interlocking teeth to assure concentricity, which appears in the drawing. Exhibit A6 contains pictures and drawings of the General Radio Type 900 connector. List prices of these sexless connectors are understood to be $30.00 each for the Dezifix and $35.00 for the Type 900.*

The Dezifix employs a sliding inner conductor spring loaded to assure contact. In joining two Dezifixes, the inner conductors meet first, and are forced to slide back as the outer flanges are pushed together. When the outer flanges meet, a coupling nut from either connector is slid across both flanges, its gripping teeth passing through notches in outer rims of the flanges, and the nut is then twisted to grip the opposite flange. The flanges gradually increase in thickness away from the notches, so that as the nut is twisted it pulls the flanges more tightly together.

In addition to improved electrical characteristics, manufacturers of the Dezifix claim that this connector is unusually flexible, because they have developed a line of adaptors which permit it to be easily coupled to existing connectors. Also, they say that the locking mechanism provides high mechani-

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*In cross-sectional drawings of some of the connectors, such as on the second page of Exhibit A6, it can be seen that there are step changes in some of the conductor diameters where plastic insulators are inserted. These step changes are to compensate for the fact that air and plastic have different dielectric properties. Introduction of a dielectric discontinuity along the path of the microwaves can have the same effect as a sudden change in shape of the conductor, causing reflections. By introducing the dielectric change and the conductor shape change at the same point, the reflective effects of one can be cancelled by those of the other so that no net reflection occurs. This compensation is analogous to that of coating a camera lens to admit more light.

cal strength so that, for instance, one instrument can be "hung" on another with Dezifix providing the only structural support between the two. The nut must be rotated only 60° to lock.

However, Hewlett-Packard engineers have commented about some less desirable characteristics in the Dezifix. To engage the nut, it is necessary to push the connector together, against the springs of the inner conductors, and at times the application of this force may be awkward, as when it might push instruments around. Also, since each conductor has its own nut, there is always one redundant nut per connection.

Hewlett-Packard engineers are also somewhat dissatisfied with the Type 900 because of its complexity and its large number of parts. The price of $35.00 is, they think, high and in view of the complexity of the Type 900, they wonder whether any company can make a profit on it. They wonder if there can be much hope that a lower price will result even if the Type 900 becomes accepted as standard and is bought in large volume.

Connector Standardization Committee

Dissatisfaction with existing standards for coaxial connectors has not been limited to Hewlett-Packard, but has been felt by other manufacturers and users of precision microwave equipment. As a result there has been formed, under the American Institute of Electrical Engineers, a subcommittee to develop standards for better coaxial connectors. The members of this committee are drawn from connector manufacturers, instrument companies, measurement laboratories and the National Bureau of Standards.

The committee met at the National Bureau of Standards in Boulder, Colorado, on September 12, 1962, and discussed possible standards for connectors. Some desirable standards were agreed upon as to mechanical and electrical characteristics of improved connectors. The mechanical standards agreed upon by the committee appear in Exhibit A7. Some dimensional specifications, such as certain diameters of conductors, were determined by the behavior of microwaves and their modes of propagation. Of the four connector sizes recommended by the committee, Hewlett-Packard engineers expect their concern

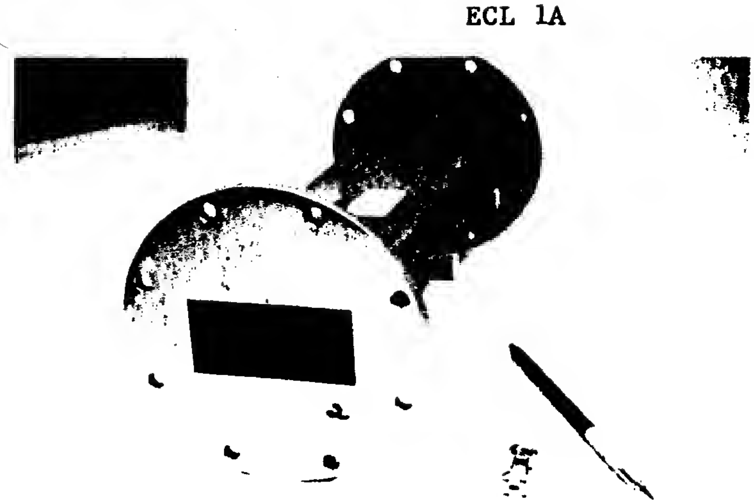
will mainly be with the smallest, since it is the size they use most. Also, they expect it would be the most difficult to design and make and could probably be scaled to larger size without much difficulty.

Some consideration was given by the committee to the Dezifix and the General Radio Type 900 connectors, although no decision regarding them was made.

The committee included among its recommendations that any connector to be adopted as standard must be offered free of any patent or royalty restrictions by its manufacturer to any other manufacturer wishing to make it. Hewlett-Packard engineers understand that General Radio has formally gone on record as willing to comply with such a requirement. Rhode and Schwarz has not given formal notice of willingness to free the Dezifix of its patent privileges, but is believed to have informally suggested such a willingness. It is also understood that Rhode and Schwarz has been continually filing patent claims on the Dezifix.

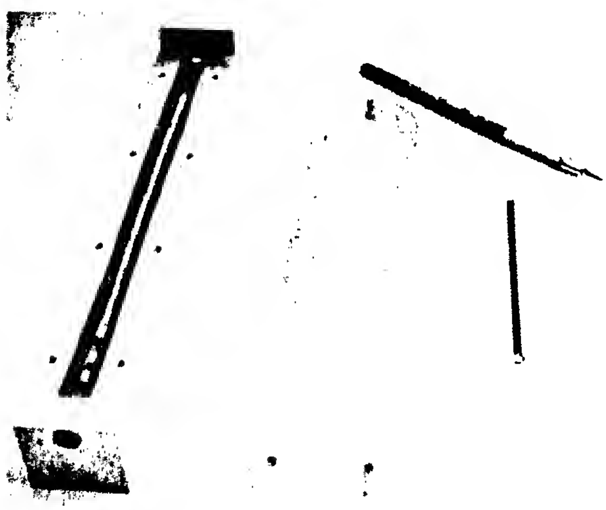
These specifications set by the committee have been given at Hewlett-Packard to a young mechanical engineer, Tony Badger. Electronic engineers at Hewlett-Packard have said it is important that the company adopt as soon as practicable a connector incorporating these improved electrical specifications, and they have asked what mechanical improvements could also be included in a better connector. Tony has been asked to submit his recommendations on the subject and explain them.

Exhibit 1 - Some Microwave Conductors



WAVEGUIDES

The large guide, with internal dimensions of 2.84 x 1.34 inches, is for S Band frequencies (2.60 - 3.95 gc.). The smaller guide, .148 x .074 inches, is for V Band (50 - 75 gc.).



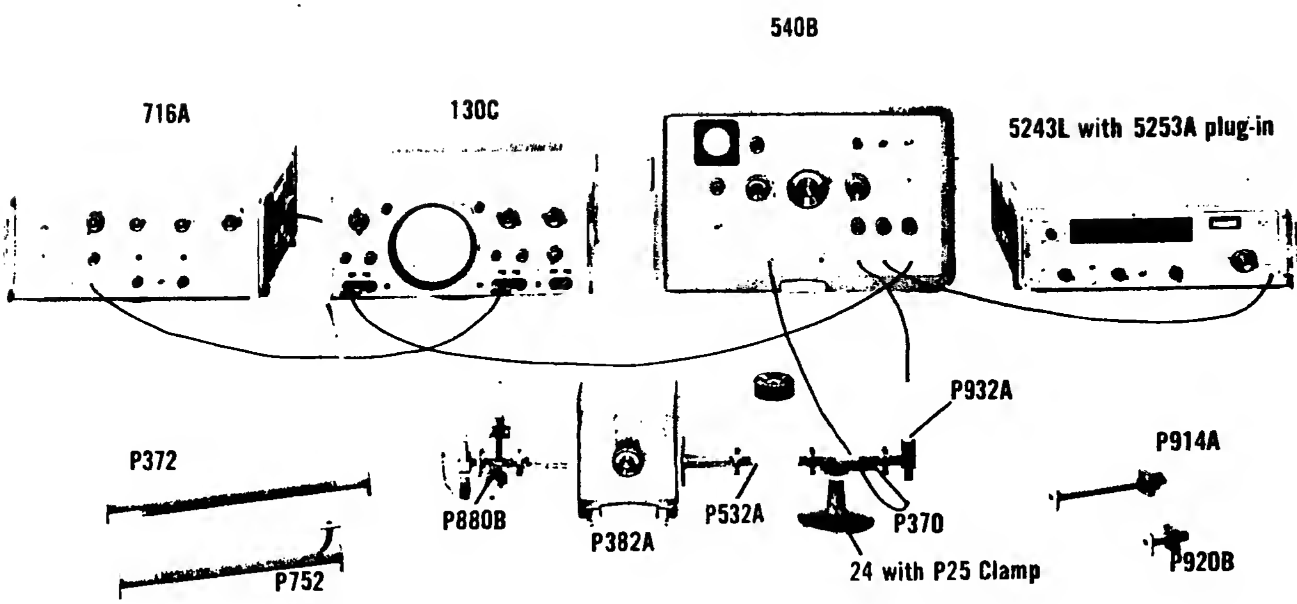
STRIPLINES

The partially assembled stripline on the left is drilled at its ends for installation of coaxial connectors.

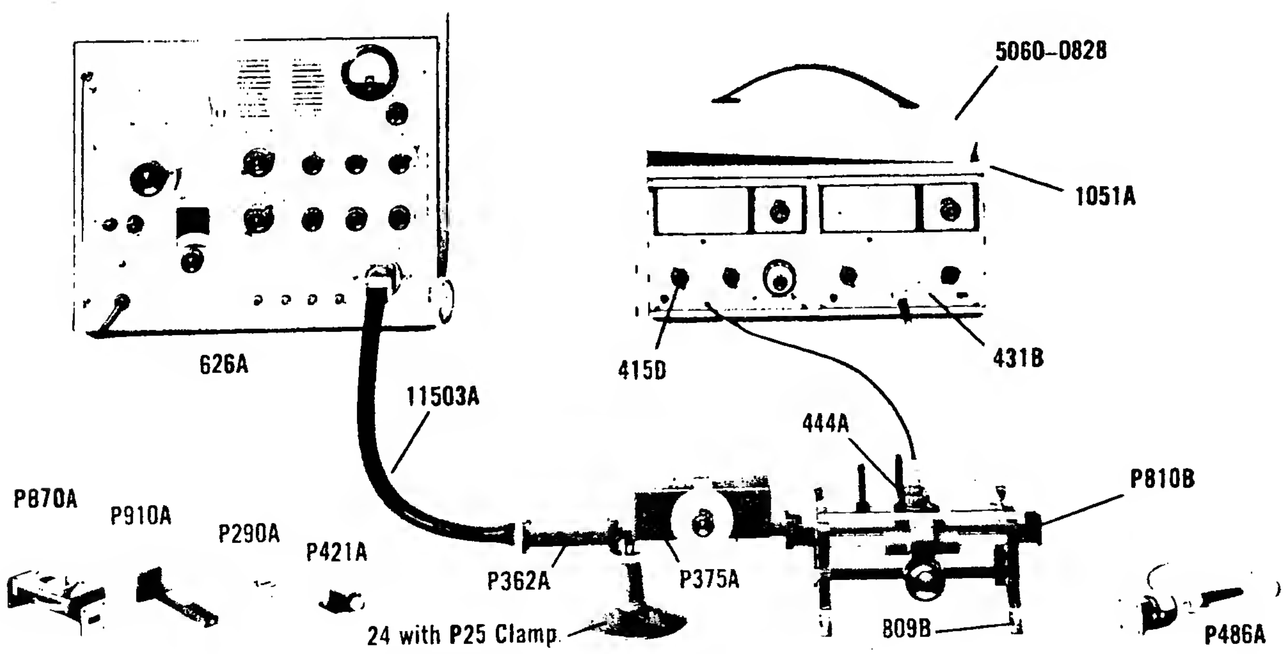
COAXIAL LINES

The flexible cable and three short lengths of rigid line are all fitted with Type N male connectors.

Exhibit 2 - Microwave Test Setups (For P Band frequencies, 12.4 - 18.0 gc.)



This group of instruments is used to calibrate an *hp* P532A Frequency Meter. A reflex klystron oscillator is used with its operating potentials furnished by an *hp* 716A Klystron Power Supply. Its frequency is swept by applying the internal sawtooth of the 716A to the repeller of the tube. The resulting FM is sufficient to show the absorptive response of the wave meter. Harmonics of the *hp* 540B Transfer Oscillator are mixed in the *hp* P932A and show up as a small "bug" on the oscilloscope trace. The counter (*hp* 5243L) is used to measure the transfer oscillator's fundamental frequency.



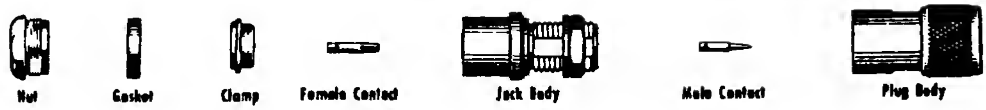
This is a typical fixed frequency setup in P-band. Note the portable microwave lab composed of an *hp* 431B Power Meter and an *hp* 415D SWR Meter installed in the *hp* 1051A Combining Case (see pages 18 and 19). Both of the instruments may be purchased with optional rechargeable batteries and then used independent of the ac line. They are useful for measurements around missiles, aircraft, antenna towers, etc.

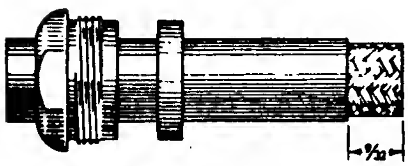
Source: Hewlett-Packard Company Catalog

Exhibit 3 - Type N Connectors

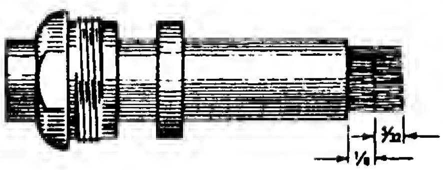
Connector Assembly Instructions

IMPROVED SERIES N

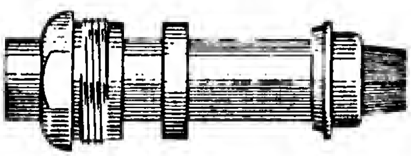




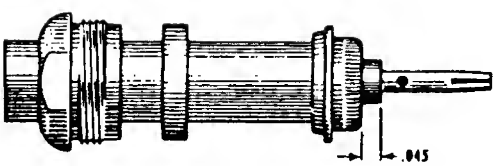
Place nut and gasket over cable and cut off jacket 9/32" from end.



Comb out braid and fold out. Cut off cable dielectric flush 1/8" from end of jacket.



Pull braid wires forward and taper toward center conductor. Place clamp over braid and push back against cable jacket.



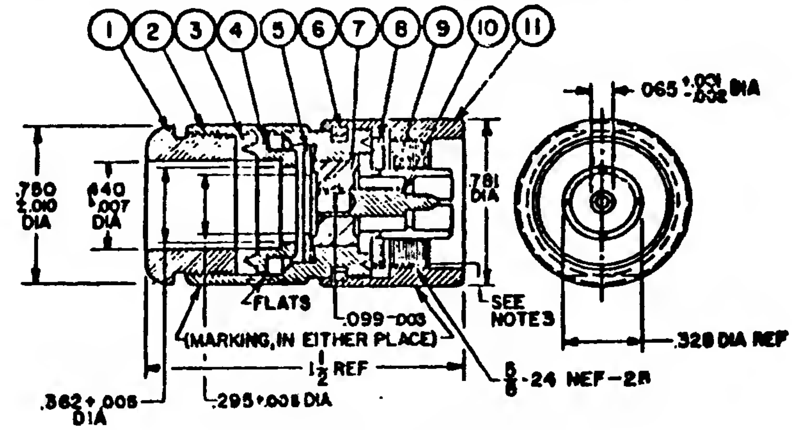
Fold back braid wires as shown, trim to proper length and form over clamp as shown. Solder contact to center conductor.

Insert cable and parts into connector body. Make sure sharp edge of clamp seats properly in gasket. Tighten nut.

Exhibit 3 (Cont) Type N

This document has been promulgated by the Department of Defense as the military standard to limit the selection of the item, product, or design covered herein in engineering, design, and procurement. This standard shall become effective not later than 90 days after the latest date of approval shown.

FED. SUP CLASS 5935



MS PART NO. MS91236-21E	FIIN 1/

1/ Federal Item Identification Number.

ITEM	DESCRIPTION	MS PART NO.	QTY
1	Electrical cable clamp	MS90225-3	1
1/2	Electrical connector shell	MS91232-1	1
3	V-groove gasket	MS90133-4	2/3
4	Shouldered and recessed washer	MS90219-3	1
5	Holding washer	MS90242-1	1
6	Spring tension washer	MS90136-1	1
7	Bushing insulator	MS90162-1	1
8	Gasket	MS90134-1	1
1/9	Electrical contact	MS90166-1	1
10	Electrical contact	MS90158-1	1
11	Coupling nut	MS90157-1	1

1/ Alternate construction of item 2 to be used with alternate construction of item 9.

2/ One required in assembly; two required as replacements.

1. All dimensions in inches.
2. Unless otherwise specified, tolerances are ±.005 on decimals.
3. Form over all around.
4. Leakage test not required.
5. A pull of 100 pounds on item 11 should not detach it from item 2.
6. A rod .121 minimum in diameter and 3/8 minimum in length to pass through item 7, after assembly in item 2, when a pressure of not more than 3 pounds is applied.
7. Plug UG-21E/U replaces plugs UG-21/U, -21A/U, -21B/U, -21C/U, and -21D/U.
8. The MS part number consists of the MS military-standard number followed by a dash number. The dash number "21E" is derived from assigned nomenclature.
9. Referenced documents shall be of the issue in effect on date of invitation for bids.
10. This standard takes precedence over documents referenced herein.

ENGINEERING DATA: WEATHERPROOF, RADIO-FREQUENCY COAXIAL CONNECTOR; NOMINAL IMPEDANCE 50 OHMS; RATED AT 1,500 VOLTS PEAK; PRACTICAL FREQUENCY LIMIT 10,000 MC/SEC; FOR USE WITH RG-8/U, -9/U, -213/U AND -214/U RF CABLES.

OK C Engg 10

APPROVED 21 September 1954 REVISED (B) 10 October 1958

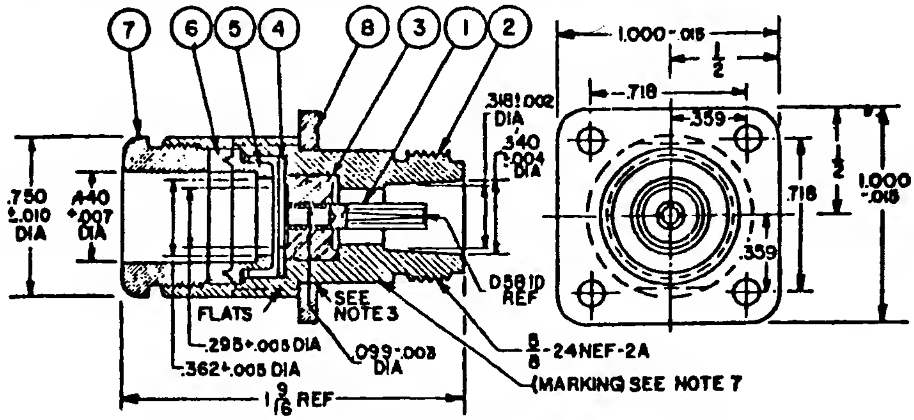
(B) ENTIRE STANDARD REVISED

CUSTODIANS:		MILITARY STANDARD	MS 91236
SigC Ships USAF		CONNECTOR, PLUG, ELECTRICAL, SERIES N, UG-21E/U	
PROCUREMENT SPECIFICATION MIL-C-71		SUPERSEDES:	SHEET 1 OF 1

Exhibit 3 (Cont.) Type N

FED. SUP CLASS 5935

This document has been promulgated by the Department of Defense as the military standard to limit the selection of the item, product, or design covered herein in engineering, design, and procurement. This standard shall become effective not later than 90 days after the latest date of approval shown.



MS PART NO. MS91237-22E	FIIN 1/
MS PART NO. MS91237-23E	FIIN 1/

1/ Federal Item Identification Number.

ITEM	DESCRIPTION	MS PART NO.	QTY
1	Electrical contact	MS90163-1	1
2	Electrical connector shell	MS91234-1	1
3	Bushing insulator	MS90162-1	1
4	Holding washer	MS90242-1	1
5	Shouldered and recessed washer	MS90219-3	1
6	V-groove gasket	MS90133-4	1/ 3
7	Electrical cable clamp	MS90225-3	1
8	Mounting panel	MS91235-1	1

1/ One required in assembly; two required as replacements.

1. All dimensions in inches.
2. Unless otherwise specified, tolerances are ±1/64 on fractions and ±.005 on decimals.
3. Silver solder all around.
4. Leakage test not required.
5. Item 8 to withstand a torque of 5 foot-pounds and a pull of 125 pounds.
6. A rod .121 minimum in diameter and 3/8 minimum in length to pass through item 3, after assembly in item 2, when a pressure of not more than 3 pounds is applied.
7. Plug UG-23E/U is identical with receptacle UG-22E/U, except that item 8 is omitted.
8. Receptacle UG-22E/U replaces panel jacks UG-22/U, -22A/U, -22B/U, -22C/U, and -22D/U.
9. Plug UG-23E/U replaces jacks UG-23/U, -23A/U, -23B/U, -23C/U, and -23D/U.
10. The MS part number consists of the MS military-standard number followed by a dash number. The dash numbers "22E" and "23E" are derived from assigned nomenclature.
11. Referenced documents shall be of the issue in effect on date of invitation for bids.
12. This standard takes precedence over documents referenced herein.

ENGINEERING DATA: WEATHERPROOF, RADIO-FREQUENCY COAXIAL CONNECTOR; NOMINAL IMPEDANCE, 50 OHMS; RATED AT 1,500 VOLTS PEAK; PRACTICAL FREQUENCY LIMIT 10,000 MC/SEC; FOR USE WITH RG-8/U, -9/U, -213/U AND -214/U RF CABLES.

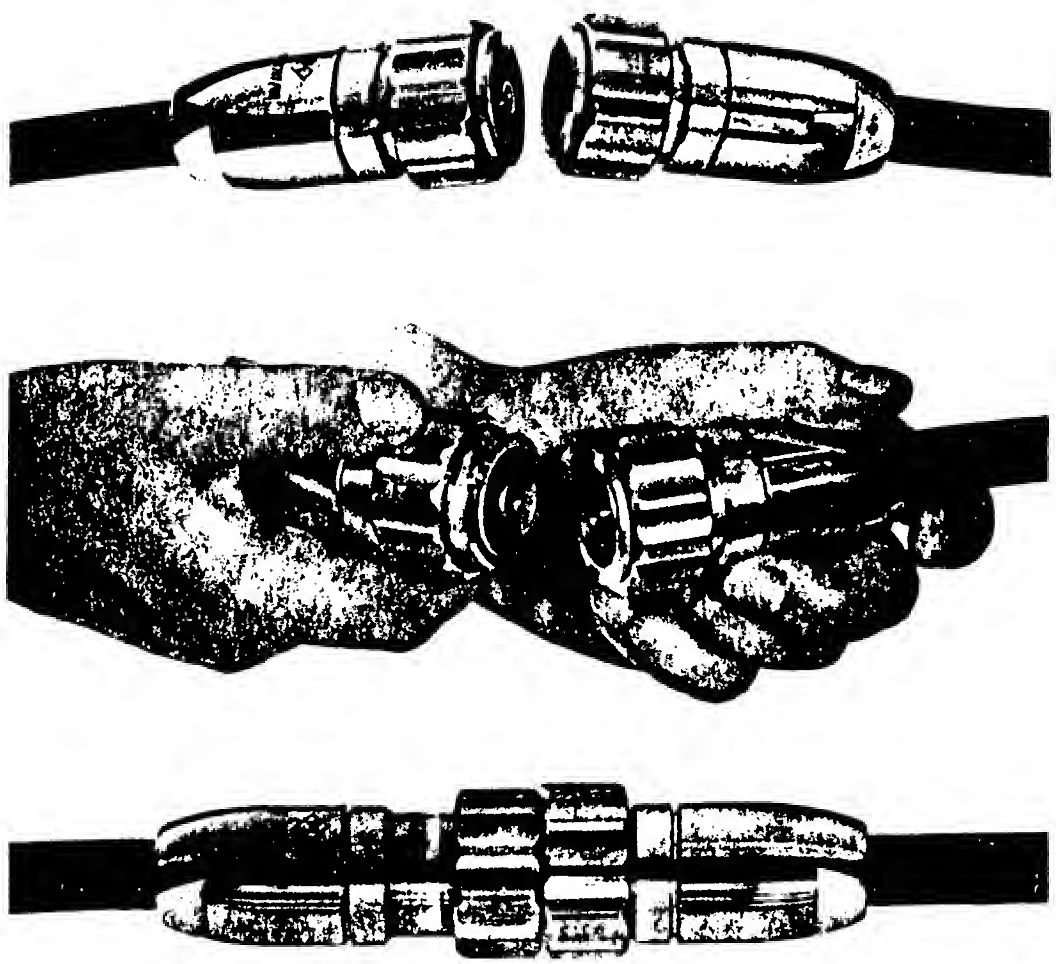
Oct 2 70

(B) ENTIRE STANDARD REVISED

APPROVED 21 September 1954 REVISED (B) 10 October 1958

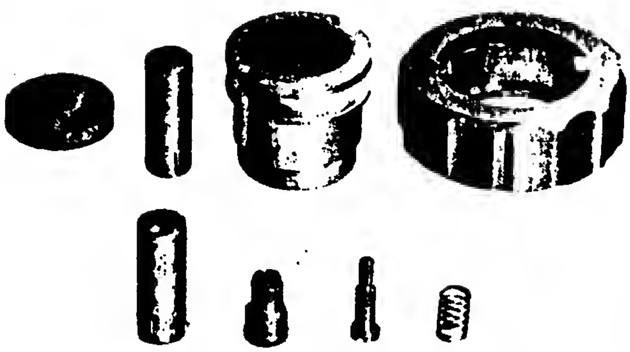
CUSTODIANS:	MILITARY STANDARD	MS 91237
SigC Ships USAF	CONNECTOR, RECEPTACLE, ELECTRICAL, SERIES N, UG-22E/U; AND CONNECTOR, PLUG, ELECTRICAL, SERIES N, UG-23E/U	
PROCUREMENT SPECIFICATION MIL-C-71	SUPERSEDES:	SHEET 1 OF 1

Exhibit 4 - Dezifix Type B

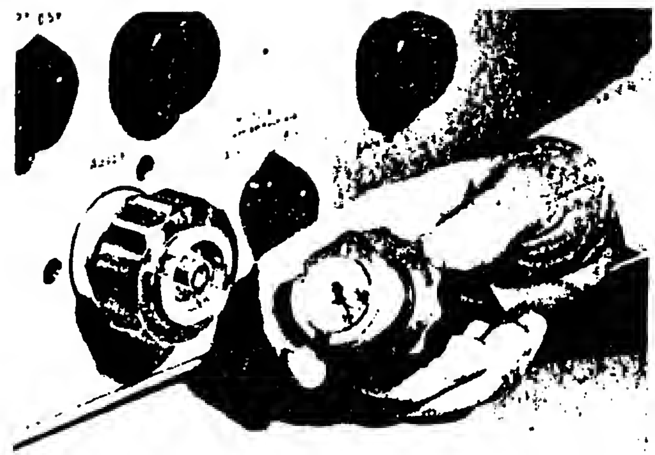


Courtesy of Rhode & Schwarz

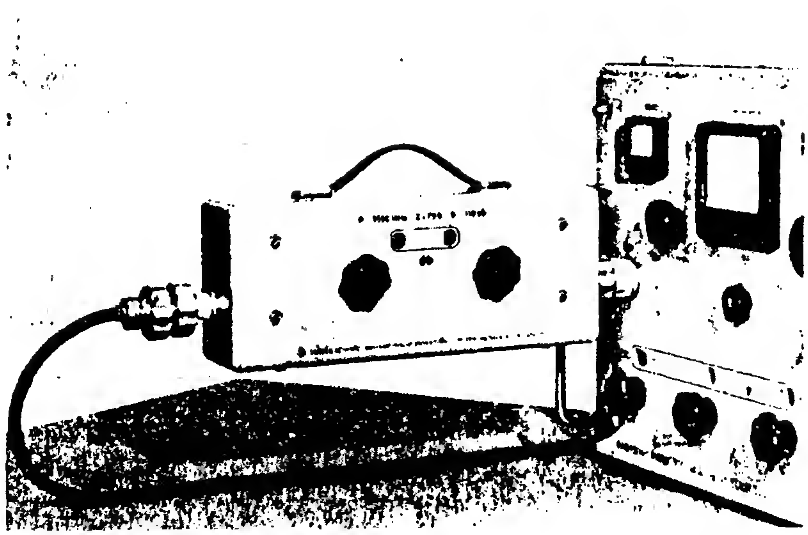
Exhibit 4 (Cont)



Component parts of the experimental connector Dezifix Size B



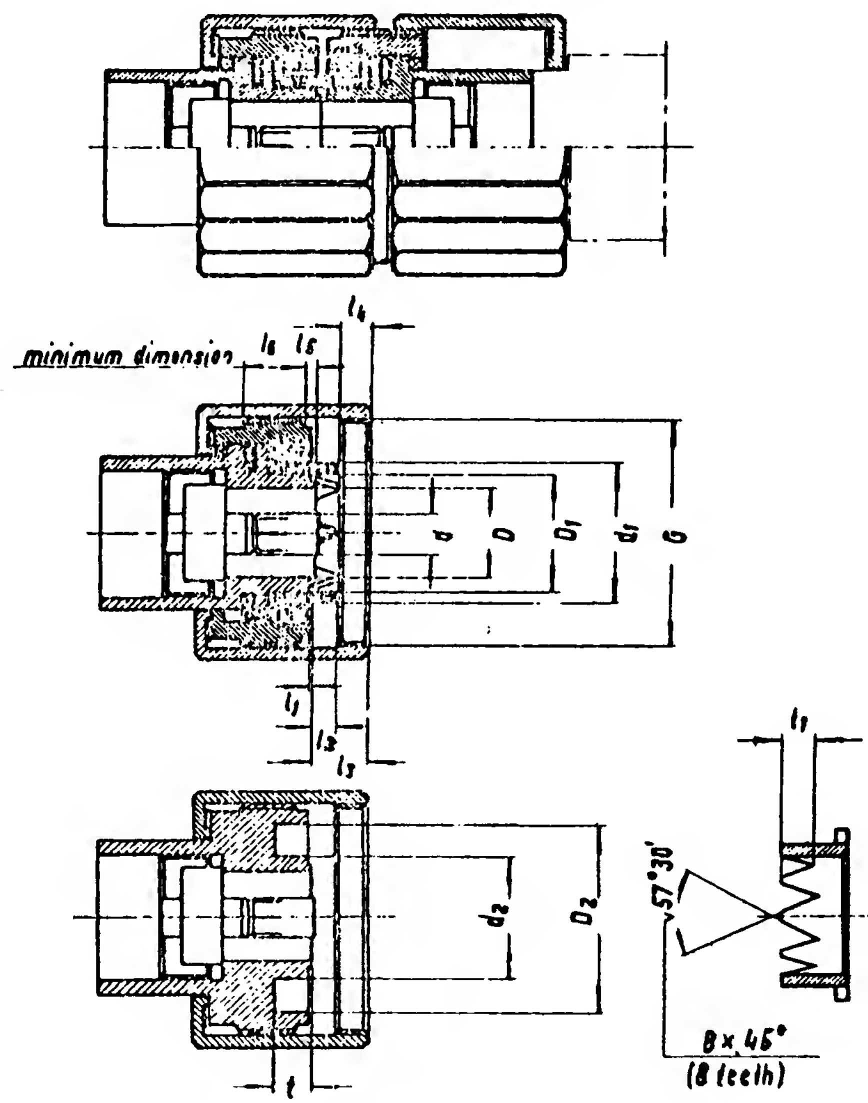
Connecting the 75 Ω cable connector to the 50 Ω connector of the signal generator does not result in any mechanical disadvantages



High mechanical stability [illegible] connected to the measuring [illegible] support

(The instrument supported by the connector weighs 5 kg.)

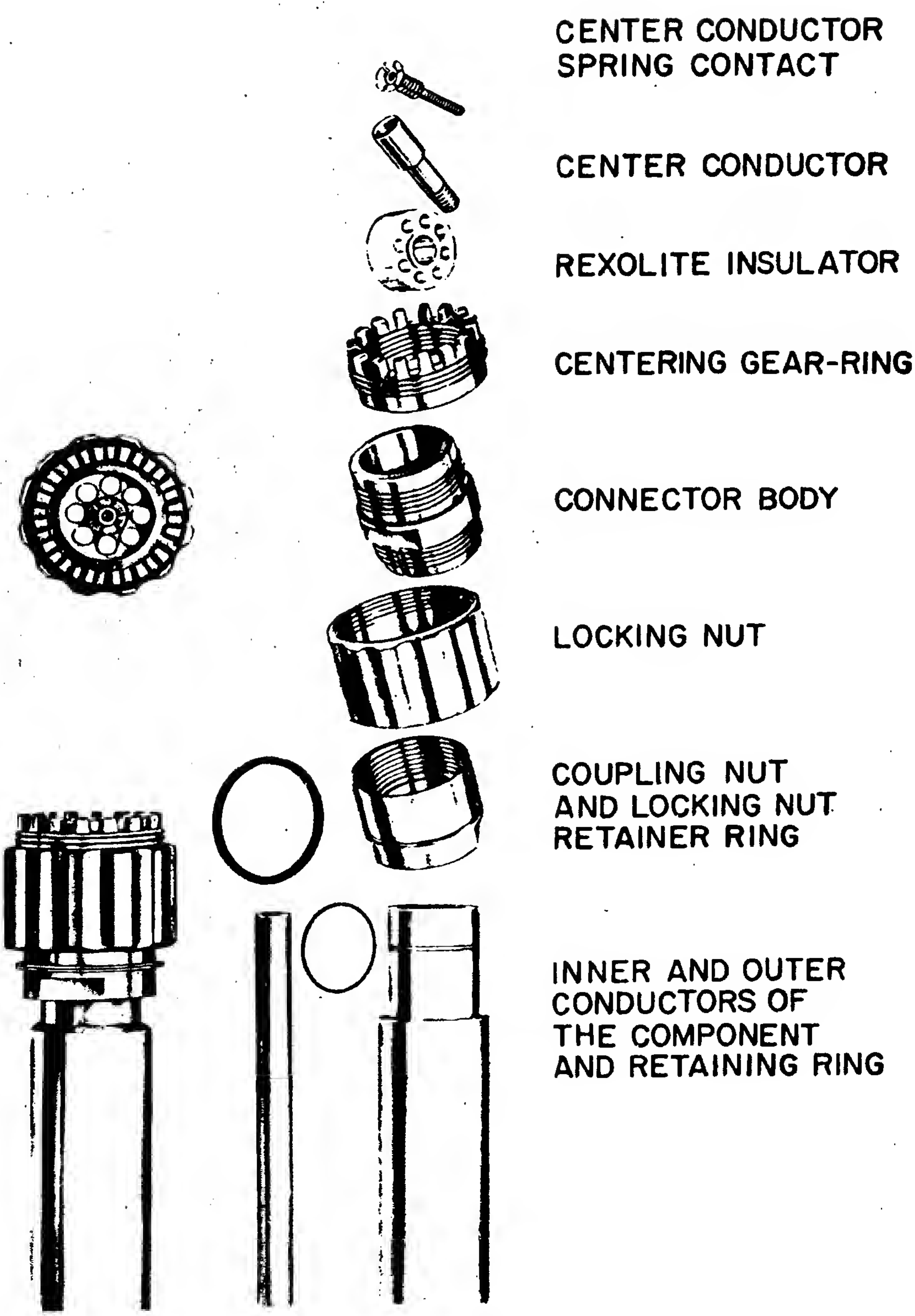
DEZIFIX TYPE A



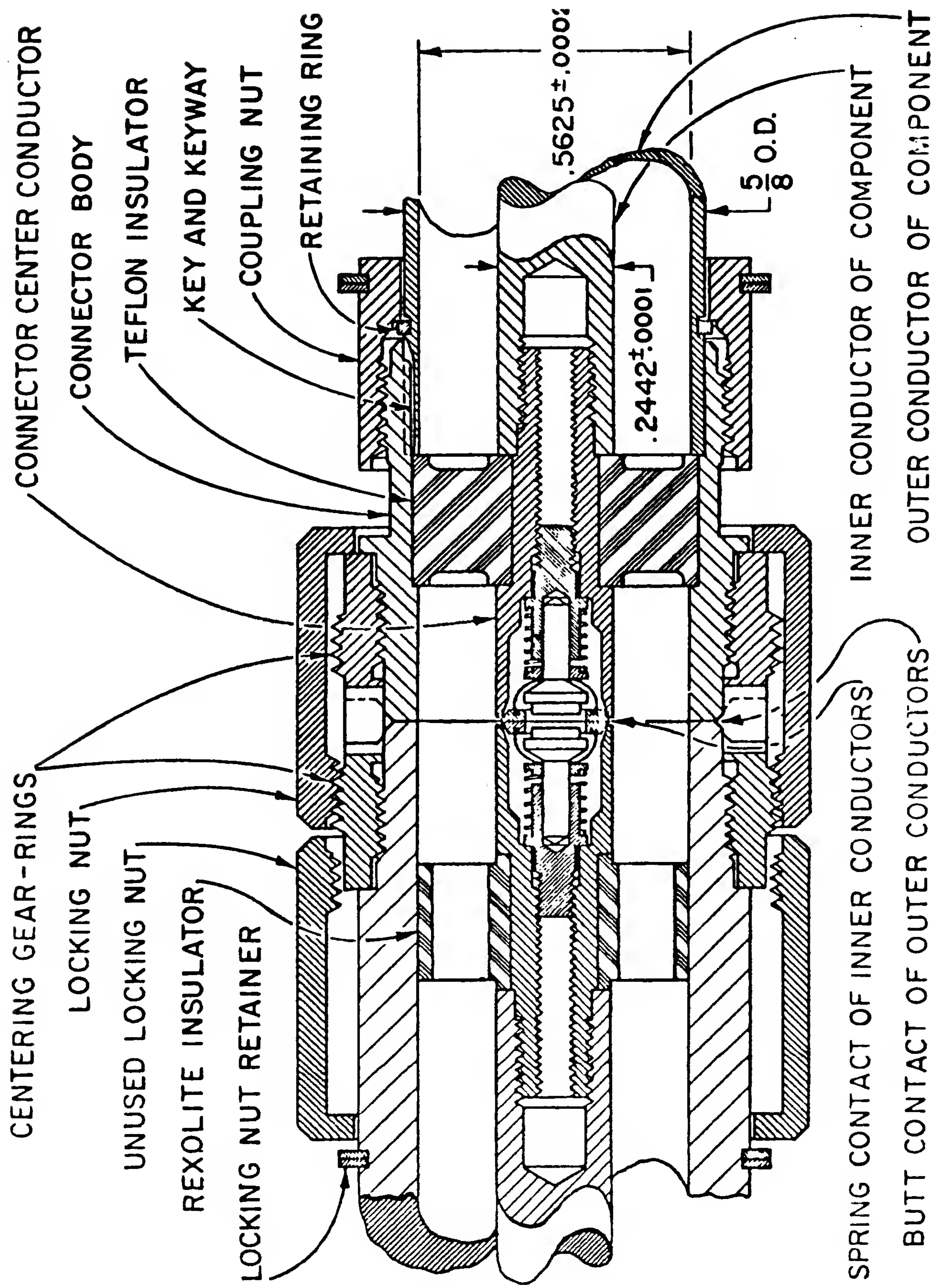
	d	d_1	d_2	D	D_1	D_2	G	t	t_1
mm tol.	3,040 ϕ ± 0,002	11 ϕ − 0,2	9 ϕ − 0,05 − 0,1	7 ϕ + 0,004	9 ϕ + 0,015	14 ϕ + 0,1	M 18 × 1 2 gängig	2,5 + 0,1	3,6 + 0,1
inch tol.	0,119684 ± 0,00008	0,433070 − 0,0078	0,34433 − 0,002 − 0,004	0,27559 ± 0,00016	0,34433 + 0,0006	0,55118 + 0,004	0,708661 0,03937 double thread	0,9842 + 0,004	0,141732 + 0,004
	l_1	l_2	l_3	l_4	l_5	l_6			
mm tol.	0,2	1,7	4	2,3 − 0,1	1,2	4			
inch tol.	0,007874	0,0669291	0,15748	0,09055 − 0,004	0,04724	0,15748			

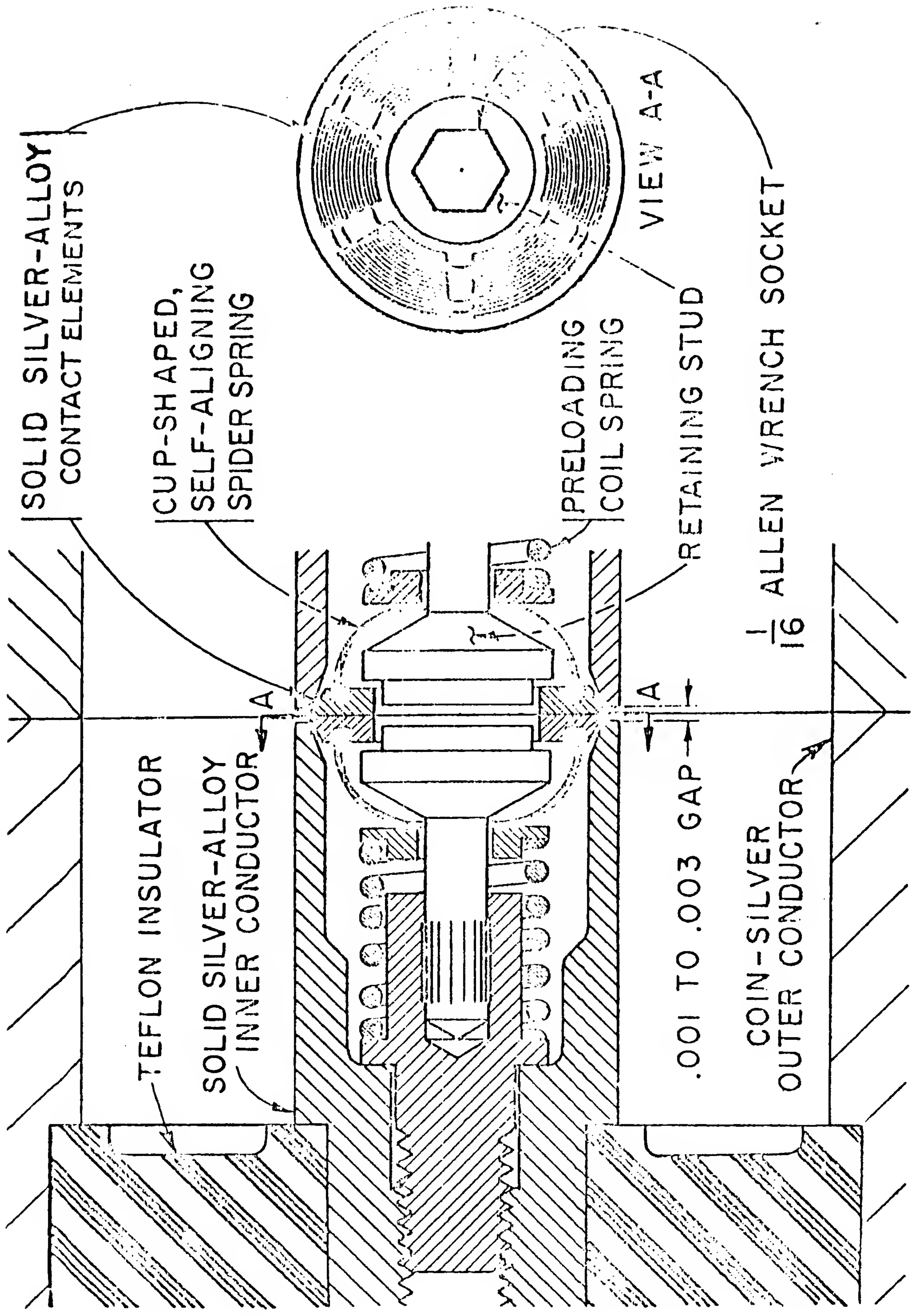
RH 3228 Bl. 6 18.6.62

- General Radio Type 900 Connector



Courtesy of General Radio Corporation


CONNECTOR CENTER CONDUCTOR
CONNECTOR BODY
TEFLON INSULATOR
KEY AND KEYWAY
COUPLING NUT
RETAINING RING
.5625±.000
5/8 O.D.
.2442±.0001
INNER CONDUCTOR OF COMPONENT
OUTER CONDUCTOR OF COMPONENT
CENTERING GEAR-RINGS
LOCKING NUT
UNUSED LOCKING NUT
REXOLITE INSULATOR
LOCKING NUT RETAINER
SPRING CONTACT OF INNER CONDUCTORS
BUTT CONTACT OF OUTER CONDUCTORS



CROSS-SECTION VIEW OF THE CONNECTOR SHOWING CONTACT SURFACES OF TWO MATED INNER CONDUCTORS.

COMMITTEE RECOMMENDATIONS ON

PRACTICES FOR PRECISION COAXIAL CONNECTORS

PART I

General Requirements and Definitions

The need is recognized for precision coaxial connectors utilizing the principle of coplanar butt joint flanges for operating frequencies in the range of 0 to 13 Gc/s. Maximum performance in a laboratory environment is a basic objective. Mechanical and electrical requirements, with appropriate definitions, are as follows:

Mechanical Requirements[1]

1. To obtain the desired performance over the frequency range of 0 to 13 Gc/s, a minimum number of coaxial line sizes will be specified.

2. In each line size, there will be two different forms of precision connectors. They are a General Precision Connector (GPC) employing a self-contained dielectric support and a Laboratory Precision Connector (LPC) using only air dielectric. The latter is used where the electrical length of the connector must be known to the highest accuracy. Provision shall be made to allow a simple conversion of the dielectric support type connector, so that its inner conductor can support the inner conductor of a connector without a dielectric support.

3. During and after mating, the front end of the inner conductors of the GPC shall be subjected only to axial forces.

4. The GPC type inner conductor dielectric support must withstand specified axial force and bending moments.

5. Provision must be made to protect the butting electrical surfaces when not mated. It should be practical to repolish or relap the butting electrical surfaces.

6. All components of the GPC type shall be captive to the connector. However, the coupling mechanism of both types must be detachable.

7. The coupling mechanism must withstand the application of the axial force and bending moment applied to the outer conductor without exceeding specified limits on VSWR, insertion loss, or leakage.

8. The mated pair of connectors must join in the same plane which is coincident with the electrical reference plane.

---

[1]Electrical Requirements also included in the recommendations are voluminous and have not been reproduced here.

PART II

Parameter to be specified

Mechanical Parameters

1. The number of line sizes. The nominal I.D. of outer conductor and nominal O.D. of inner conductor and tolerances for each size.

2. Maximum axial force which may be applied to a supported inner conductor when brought into coplanar condition.

3. Maximum axial displacement of the supported inner conductor, resulting from application of a specified axial force.

4. Maximum angular deflection of supported inner conductor arising from the application of a specified bending moment referred to the center of the dielectric support and applied to the back end of the inner conductor.

5. Operating range of temperature, relative humidity, and pressure.

6. Non-operating temperature range which will not cause non-compliance with the specification in the operating range.

7. Number of complete connections - disconnections of a connector pair under laboratory conditions which will not cause non-compliance with the specification in the operating range.

8. Critical dimensions and tolerances for the mating surfaces and for attaching the coupling mechanism or for integral coupling means.

9. The connectors must be sexless. Any one connector of the same line size must be capable of being mated, without adaptors, with any other connector of the same line size.

10. To connect the rear of the connector to a transmission line, the manufacturer of the connector must supply a drawing showing the form, dimensions, and tolerances. Recommended materials and finishes for the mating portion of the transmission line should also be furnished.

PART III

Parameter Limits

Mechanical Parameters

1. Conductor diameter and tolerances

	I.D. of outer conductor		O.D. of inner conductor	
	Inches	Centimeters	Inches	Centimeters
Line Size I	0.8268"±0.0003"	2.100±8μ	0.3587"±0.0002"	0.9110±4μ
Line Size II	0.7500"±0.0002"	1.905±5μ	0.3257"±0.0001"	0.8273±3μ
Line Size III	0.5625"±0.0002"	1.429±5μ	0.24425"±0.0001"	0.6204±3μ
Line Size IV	0.2762"±0.0005"	0.7015±13μ	0.1200"±0.0002"	0.3048±5μ

2. Inner conductor mating force limits

When two connectors are mated, the axial force exerted by the contact mechanism on the inner conductor of a GPC connector shall be less than the following:

Line Size I	5 lbs.	2.27 kg
Line Size II	2 lbs.	.907 kg
Line Size III	2 lbs.	.907 kg
Line Size IV	1 lbs.	.454 kg

3. Inner conductor applied force limits

The inner conductor of a GPC connector shall be displaced axially less than .001" when the following axial force is applied.

Line Size I	10 lbs.	4.54 kg
Line Size II	5 lbs.	2.27 kg
Line Size III	5 lbs.	2.27 kg
Line Size IV	2 lbs.	.907 kg

4. Center Conductor Angular Deflection

The angular deflection, of the inner conductor for Line Sizes I to III of a GPC connector, occuring from the application of a bending moment referred to the center of the dielectric support and applied to the back end of the inner conductor shall be less than 1/2° at the front end of the connector when a 0.1 ft. lb. (1.36×10^6 dyne centimeters) bending moment is applied.

5. Environmental conditions -- operating

The range of environmental conditions over which the performance of the connectors shall remain within electrical specifications is as follows:

Temperature	13 to 33° C
Humidity	20 to 80% R.H.
Altitude	0 to 6000 ft.
Pressure	± 20 mm. Hg from normal at operating altitude

6. Environmental conditions -- non-operating

The non-operating temperature range shall be from -40 to +70°C.

7. Connect/disconnect life

The electrical performance shall remain within specifications when the connector is subjected to 1000 complete connection cycles.

Engineering Case Library

ECL 1B

Hewlett-Packard Company (B)

History of a Coaxial Microwave Connector Design

The following comments of Mr. Anthony Badger, a mechanical engineer at the Hewlett-Packard Company, describe the approach he took to the problem of designing a "better" coaxial microwave connector. Attached following his comments are the sketches Mr. Badger drew in working out his design and also pictures of his experimental hardware and of the final product.

Prepared in the Design Division, Department of Mechanical Engineering by Karl H. Vesper from comments by Anthony Badger.

The design job was assigned to Mr. Badger on March 22, 1963. In summary, he first spent two days familiarizing himself with the problem before sketching ideas for its solution. Within four hours of starting to sketch, he had settled upon use of interlocking nuts, the main feature of his connector, and had roughed out the design. Fabrication of the first prototypes took 18 days from submission of an order to the shop until their completion. Prototype testing took approximately 12 months. At the same time, refinements and variations were being added. As of April, 1964, Hewlett-Packard was negotiating to bring about acceptance and mass production of the product. The problems of gaining acceptance are great because coaxial connectors are so widely used, but Hewlett-Packard believed the merits of Mr. Badger's design sufficient to make it a standard of the industry.

"My first step, on being asked to do the mechanical design of an improved coaxial connector," said Mr. Badger, "was to learn all I could about the problem. I looked closely at the basic functions the connector had to perform, and tried to satisfy all my curiosities. From looking at the problems of the existing standard connector and talking with electrical engineers, I drew conclusions about the fact that it should be sexless, what alignments it should have, what it should fit on, and so forth.

"So before starting to form ideas for the design I had in mind a fairly clear set of specifications. Later, after I had worked out the basic design, I wrote down a set of specifications with which to evaluate the design. (A copy of Mr. Badger's later specification list appears as Exhibit B1. The items checked on this list are those he remembered as having clearly in mind when starting his designs. The remainder were added later as a result of further thinking and comments by other Hewlett-Packard engineers in response to Mr. Badger's design sketches).

"I made it a point initially not to look at others' solutions to the problem. We had a file with information on proposed sexless connectors, but I avoided seeing it to keep my thinking from being too channeled. I think this was very important. My design turned out to be quite different from theirs, and it might not have come to me if I had seen theirs. My plan was first to develop my own best approach to the problem and then to look at the others' designs to get ideas for further improvement.

"I tried to break the problem into steps and tackle the major crux first. This crux seemed to be the alignment and pulling together of the outer conductors. If I could accomplish this, I thought the rest would fall in fairly easily. So the problem in its most basic form seemed to be to design a sexless coupling device.

"Next, I undertook to do 'dissociated thinking' about the basic problem of joining things together. I made a list of all the ways I could think of to join things, putting the ideas down on paper as quickly as possible and avoiding any tendency to criticize them. I tried to let each idea spread in as many directions as possible."

A copy of Mr. Badger's list of ways of joining appears as Exhibit B2.

"Then from this list I started selecting what seemed to be some of the more promising ideas and exploring how they might be carried out. I asked how each idea would solve the basic problem.

"Somehow I got stuck on the idea of rotation. I wrote down rotation, the idea of a screw, and started making quick sketches on the subject as they occurred. I looked at non-rotation ideas, levers and clips of various types, but these somehow did not seem 'clean'. I also considered but rejected ideas of redundant parts and loose parts. Some kind of snap arrangement, I thought, might be cleaner, but it wouldn't have enough mechanical advantage. So I kept

coming back to the idea of rotation. The problem of a screw, however, was to make it sexless."

The sketches with which Mr. Badger explored some of these alternative approaches are reproduced in Exhibit B3. Pointing to the sketch page numbered 11 in Exhibit B3. Mr. Badger recalled, "As soon as I started thinking of rotating nuts, I realized they'd overlap the joint. It followed that the alignment problem would be solved. At that point, (Mr. Badger pointed to the sketch page numbered 13) I sort of fell into the idea of the final design. My thinking somehow shifted from external to internal gripping. There are really only a few ways of fastening sexlessly and with rotation. I had considered the idea of extraneous parts such as nuts which slip over, but these I quickly rejected to look for something more clean and simple. I thought about external cams, then somehow got the idea of tangs. I'm not sure how this idea emerged.

"Even when I had the basic idea, however, it was hard for me to visualize. I had a feeling about how it could work, but wasn't really sure of the principle and couldn't really see it. If someone had asked me to explain the idea I couldn't have. I couldn't draw it either. So I made a cardboard model in three dimensions to see how things could fit together. Then I made isometric drawings to help further in visualizing.

"I started to run some calculations regarding the force on the joint obtainable from a reasonable torque on the nut. It was also necessary to select a ramp angle which would be self-locking. This could be determined from the coefficient of friction of the materials involved. It turned out that my initial choice of ramp angle was very nearly that ultimately used in the final design." (A copy of Mr. Badger's notes on this problem appears in Exhibit B4.

"The radial alignment didn't look like much of a problem. This could be controlled by accuracy of the bore in the nut. It could be seen that the tangs

would tend to bend radially inward as they were tightened, and this would make concentricity certain.

"Stresses also didn't seem as if they would pose substantial problems, and for this reason I didn't run any stress calculations at all. It seemed to me that there would be so many assumptions needed that the stress calculations would be highly subject to error, and that therefore intuitive 'feel' would be better and prototype testing still better.

"I made drawings four times full size (illustrated in Exhibit B5) complete with all dimensions and sent them to the model shop, where the job of fabricating the prototype was expected to take about a week. Once the drawings were out, I left the job to the shop. I didn't visit the shop or interfere with the fabrication in any way once it was started.

"While this fabrication was going on, a strong fear struck me that the design might somehow be all wrong. Maybe the conductor wasn't really sexless. The tangs, after all, were really just threads. But yet they had to fit into one another. I began to worry that they might just oppose each other and that it might be impossible to make such a scheme work.

"At the same time, the word was getting around about the design I'd worked out and some of the electrical engineers began to show a lot of interest in it. Initially, I had kept my ideas completely to myself, as I always do when trying to come up with new approaches, unless I'm completely stuck at an impasse. Other people can completely kill an idea before it's had a chance, just by being skeptical and throwing a little cold water on it. But once the idea is worked out, they can help to refine it. So when the drawings were done I welcomed the chance to discuss it with others. They immediately told me of more features they wanted the connector to have.

"One additional feature requested, for instance, was that the nut be

easily removable, instead of permanently fixed to the line as I had assumed. (Permanent attachment assumption is illustrated in Mr. Badger's drawing shown in Exhibit B6.) To meet this desire I went through a number of ideas (illustrated in Mr. Badger's notes appearing in Exhibit B7a. I liked the idea of a snap-ring but couldn't see a good way to apply it. A representative of the Truarc Company, Mr. Paul Vapner, answered my call for assistance and suggested the idea of inserting the snap-ring by reaching in through the front of the nut, a much better arrangement than I had been able to think of.

"Meanwhile, I had also gone to work on design of the inner conductor joint. I knew a plastic bead was needed to keep the inner conductor centered. The problem became 'How do you make contact at the interface between the two inner conductors to be joined?' I developed lists and a collection of sketches on different approaches, just as on the outer conductor problem. But on the inner conductor several designs seemed worth carrying to the prototype and testing stage, rather than just one as with the nut.

"I tried using a bellows, but this turned out to be too difficult to manufacture. I also tried using beads as axial springs to push the inner conductors against one another. The fault with that approach turned out to be cold flow of the plastic causing the contact pressure to drop during the first 48 hours. I did quite a bit of testing of the cold flow properties of bead materials before giving up that approach.

"Finally, I centered on the approach of using a collet springing from inside a hollow center conductor. I spent a whole day analyzing to determine the dimensions required to allow it to move axially while springing open radially a sufficient amount to stop itself at the proper limit of axial travel so it wouldn't fall out of the center conductor. This finally worked out with an assembly requiring only two parts. A sketch of the collet mechanism appears in Exhibit B7b.

"Only after the designs were in the model shop did I look at competitor's designs for more ideas. My conclusion was that my designs were superior. They would be simpler, cleaner, easier to use and cheaper to make.

"When the model shop sent over the first prototype, I tried it, and it worked. Then I did more thinking about how to manufacture it economically, by using extrusions and so forth, and I devised ways of testing it mechanically for performance and wear. For instance, I designed a machine to cycle the nut through fastening and unfastening to see how it would last and what metal treatment such as anodizing would help extend life. I had to see the electrical engineers and get them to test the connector for electrical performance. All this testing helped determine exactly what the optimum dimensions and tolerances should be. About 95% of the total design time was spent on this sort of refinement.

"After looking at a wide variety of ways to manufacture the connector, I settled on the use of an anodized aluminum extrusion for the nut and screw machined parts for the rest. The extrusion die required would cost around $465 and the aluminum about 1/10 cents per connector. Screw machine time on the nut would be around 15 seconds. In total, I estimated the total direct cost of the nut would be about 15 cents, and that of the inner conductor about 20 cents. These costs were determined by sending drawings of the parts with several alternative configurations out to machine shops with a request for quotations." (An illustrative example of one of the requests and the reply received appears in Exhibit B8.) Drawings illustrating subsequent design modifications up to the present appear in Exhibit B9.

"Now we seem to have the design pretty well worked out. The next question is how to put it on the market. There is resistance due to the habits of past practices and to the competition from other companies advocating their designs.

Our management is trying to get one of the big connector manufacturers to adopt our design. Unfortunately, this manufacturer has already made a deal for producing one of the competing sexless designs. When we showed them our design, they were pretty shaken up about the deal they had just made. Apparently they're now trying to figure out what to do about it. If our design were not substantially better than the other designs, I'm sure they'd go ahead with their other deal. But because it is substantially better, they may decide to scrap their other investment and manufacture our design. It remains to be seen."

Later Developments

In August of 1964 it was announced that a new connector, manufactured by the Amphenol-Borg Electronics Corporation under patent rights acquired from the Hewlett-Packard Company, was available for purchase. Excerpts from a brochure advertising the new product appear in Exhibit B10.* The Bulletin also carried the following statement:

> Reference to the Subcommittee on Precision Coaxial Connectors of the TC, Electronic and High Frequency Instruments, IEEE in this bulletin is necessary for explanation and does not imply subcommittee endorsement of the Amphenol Precision Coaxial Connector. Representations made on specifications are the sole responsibility of Amphenol-Borg Electronics Corporation.

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*"VSWR" means voltage standing wave ratio .

1.)

✓ a.) SEXLESS

b.) MUST BE ABLE TO ASSEMBLE JUNCTION WITH ANY ANGULAR RELATIONSHIP BETWEEN CONDUCTORS. I.E. LOCKING DEVICE SHOULD BE FREE TO ROTATE RELATIVE TO CONDUCTORS.

c.) LOCK WITH LESS THAN 90° ROTATION OF LOCKING DEVICE, OR HAVE A QUICK ACTING SNAP ACTION

✓ d.) A MINIMUM OF PARTS & ALL PARTS MUST BE SELF CONTAINED IN THE UNIT. I.E. NO LOOSE PARTS. AND IF POSSIBLE, THERE SHOULD BE NO REDUNDANCY IN WORKING PARTS.

e.) JOINT FACE MUST BE EASILY RECONDITIONED IN THE FIELD.

✓ f.) LOW R.F. LEAKAGE

✓ g.)
"C" CONDUCTOR DIA .120 $^{\pm .0002}$ DIA
"O" CONDUCTOR DIA .276 $^{\pm .0002}$ DIA
CONCENTRICITY OUTER "C" TO INNER .001 T.I.R.
CONCENTRICITY INNER "O" TO INNER .001 T.I.R.
CONCENTRICITY INNER TO OUTER .0005 T.I.R.

h.) MAX. JUNCTION DIMENSIONS:
1.) O.D. 1.000 ← later
2.) LENGTH 1.500 ←

2.

✓ i.) C CONDUCTOR & OUTER CONDUCTOR MUST MAKE GOOD ELECTRICAL CONTACT WHEN JUNCTION IS COMPLETE.

✓ j.) MUST BE SMOOTH ELECTRICAL TRANSITION AT JUNCTION I.E. VSWR 1.02 D.C → 12.5 GC

k.) ENVIRONMENTAL:
1.) 50,000 CYCLES
2.) −28°C — +65°C OPERATING RANGE
3.) WITHSTAND 50,000 CPM VIBRATION MAX. AMPLITUDE OF .062

l.) MANUFACTURING COST OF A COMPLETE JUNCTION UNDER $5.00

m.) INDUSTRIAL DESIGN CONSIDERATIONS MUST BE CONSIDERED.

← later

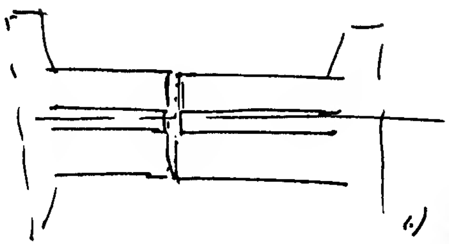
Exhibit B2

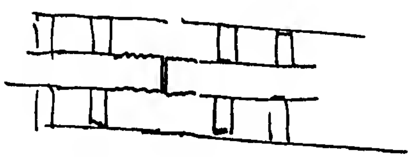
Ways of Joining

ECL B1

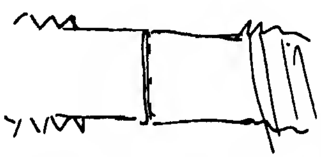
①

P 1





1.) MOLECULE
2.) SEED
3.) IVY - (SUCTION ROOTS GROW DOWN)
4.) SNAILS - FLY
5.) BURRS (VELCROSE PAD)
6.) ATOM
7.) ABALONE
8.)



1) ELECTRICALLY — MAGNET
2) STICKY
3) SUCTION
4) MAGNET
5) SCREW
6) BOLT
7) CLAMP
8) PRESS
9) SLIP
10) WELD

11.) GLUE
12.) VELCROX TAPE
13.) WRAP
14.) GRAFT
15.) SNAP
16) AIR HOSE
17.) RADIATOR HOSE BAND
18.) SOLDER
19.) LOCK

P 2

20.) SPRING 

TAPER

21) SLIDE SLEEVE
22.) MOLD
23) CAST
24.) STATIC ELECT.
25.) HEAT
26.) KNIT
27.) SEW
28.) ZIP
29.) PIN

gas can top

30.) LOCATE
31) WIRE
32) EXPLODE
33). KEY
34) SPLINE

SPLINE, KEYWAY
DOWEL PIN

35) LOCATION
36.)

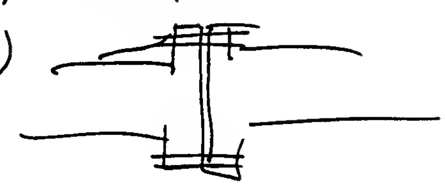
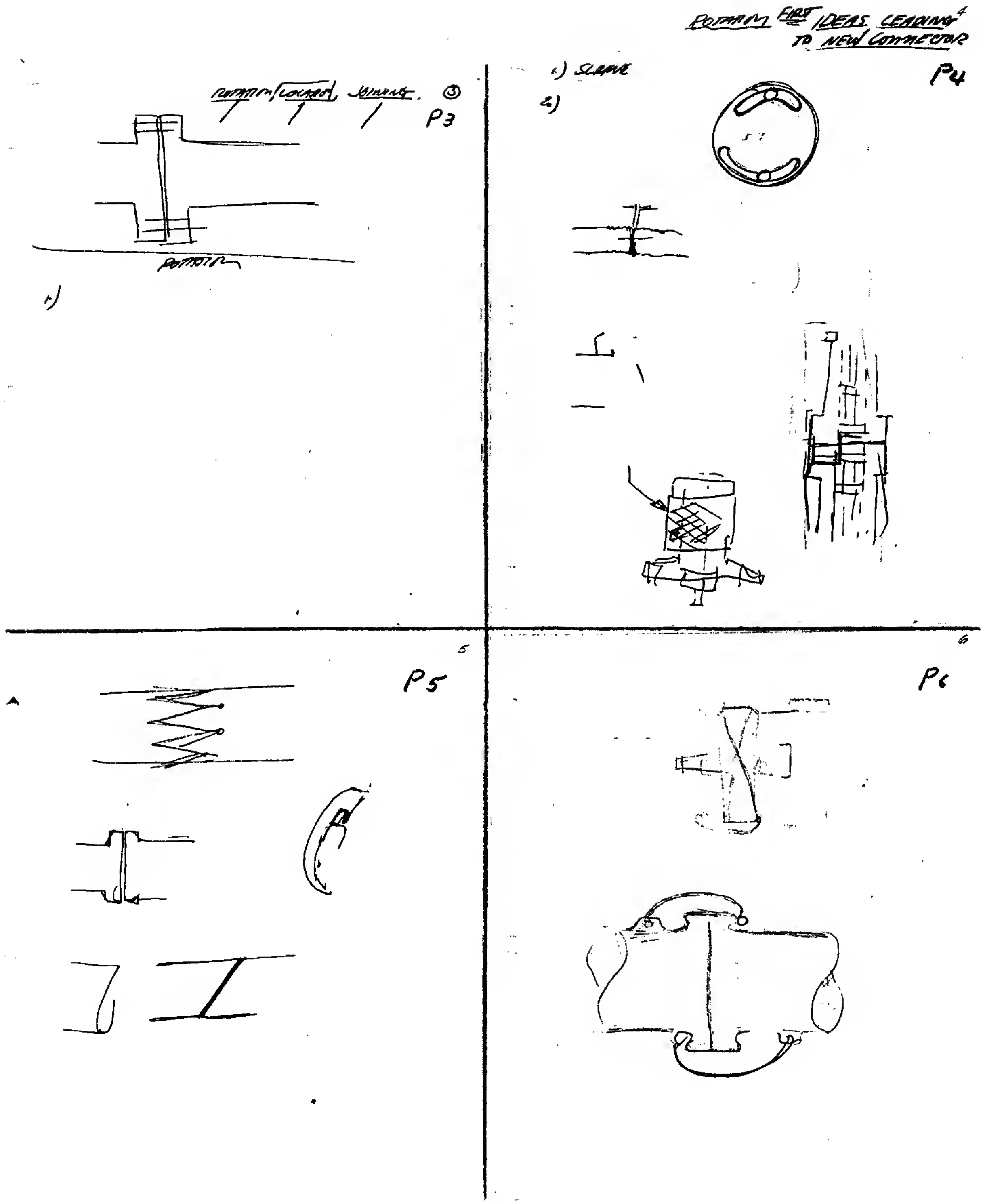
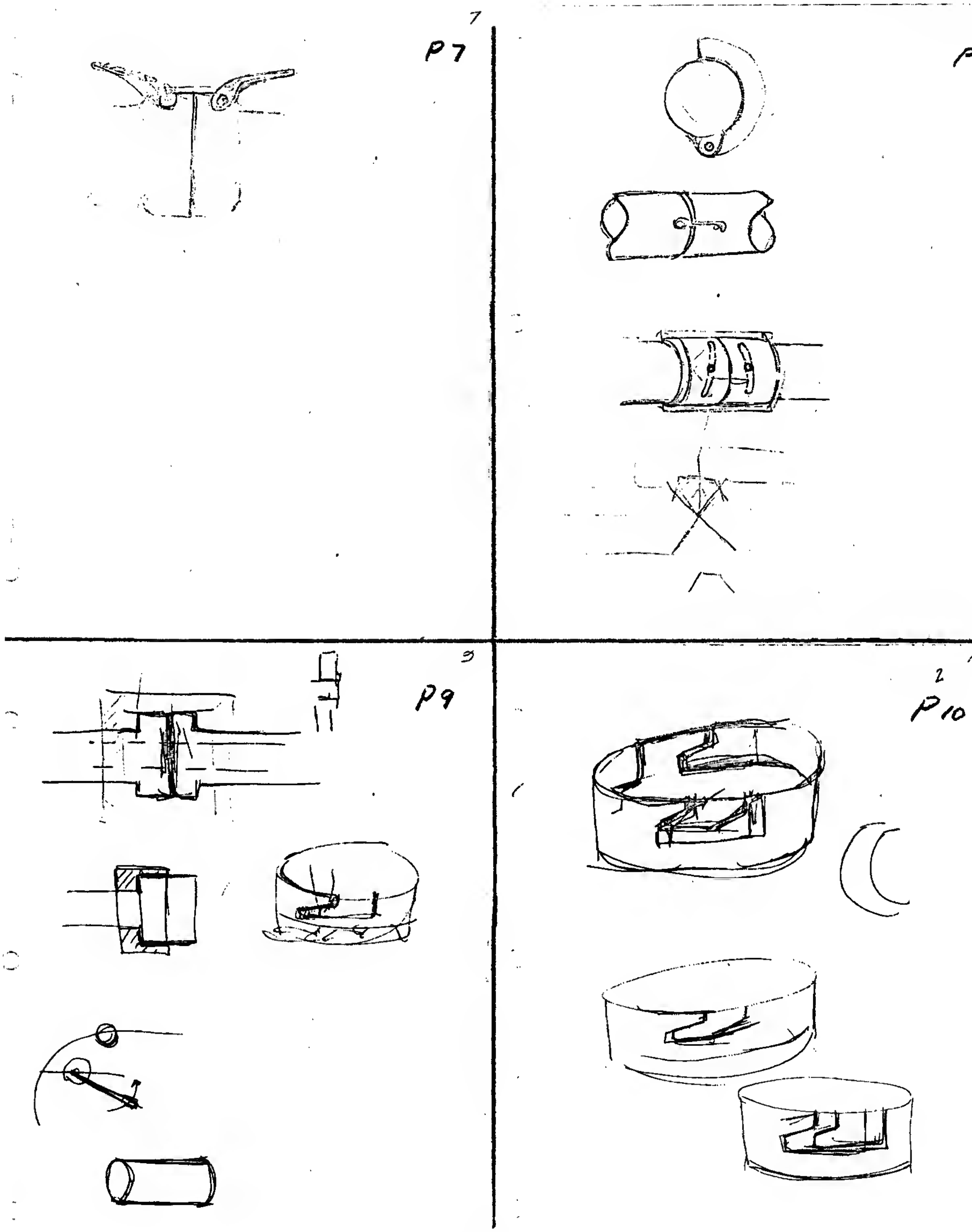


Exhibit B3

ECL 1B

Nut Design Sketches




P7
P8
P9
P10

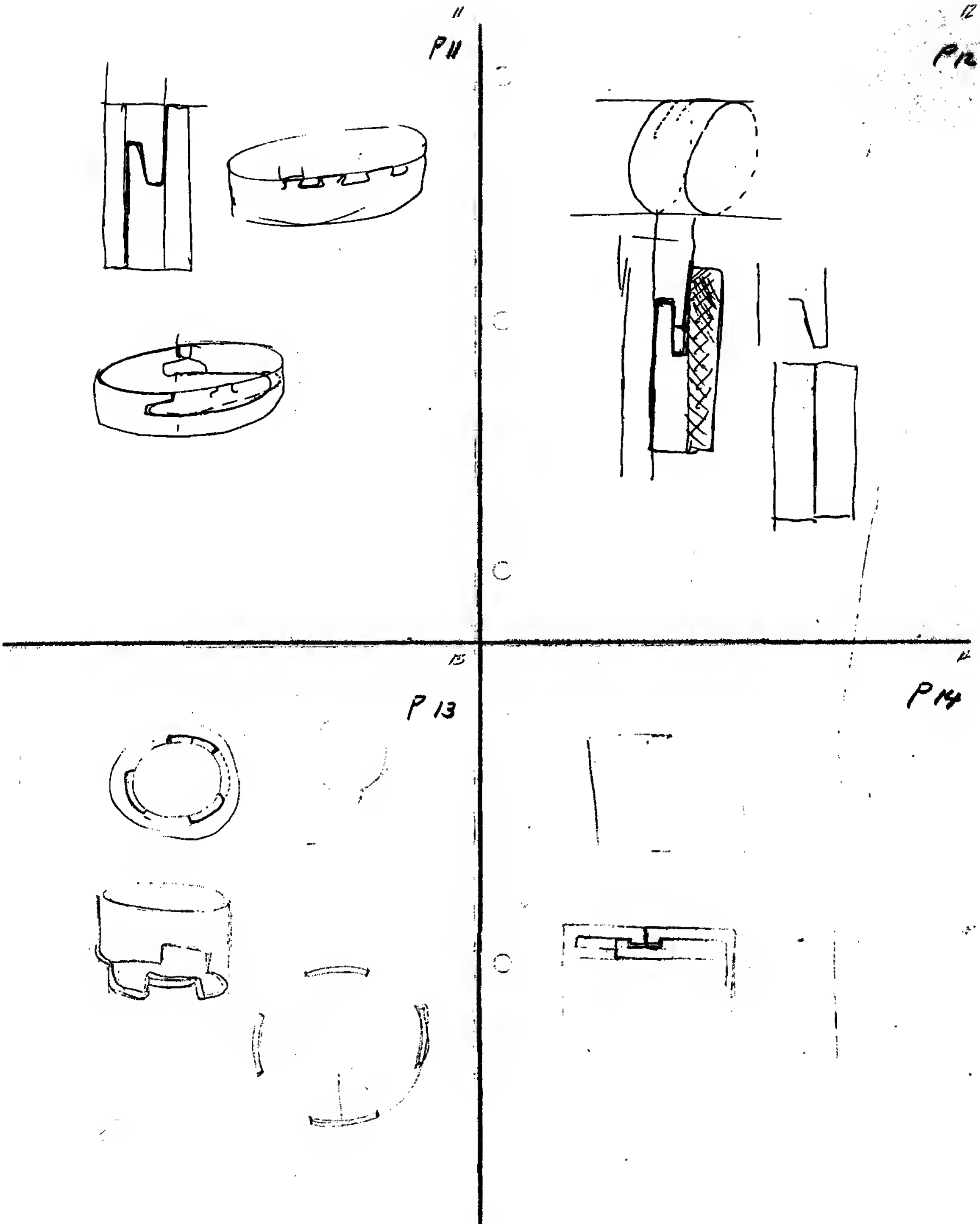
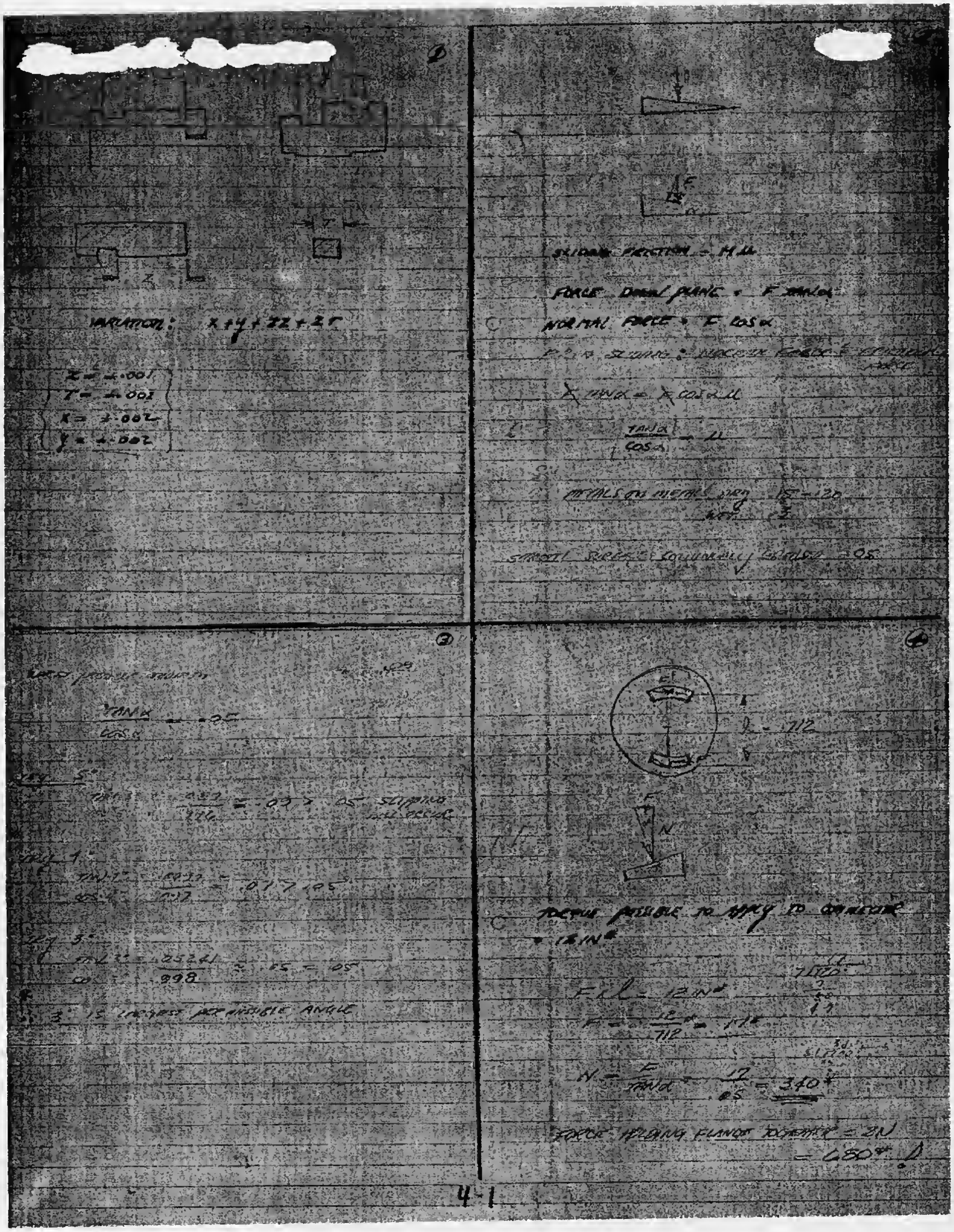

11
P11
12
P12
13
P 13
14
P14

Exhibit B4

Nut Calculations



①

VARIATION: $X + Y + 2Z + 2T$

$Z = \pm .001$
$T = \pm .001$
$X = \pm .002$
$Y = \pm .002$

②

SLIDING FRICTION = $N\mu$

FORCE DOWN PLANE = $F \tan\alpha$

NORMAL FORCE = $F \cos\alpha$

FOR NO SLIDING: [illegible] FORCE [illegible]

$F \tan\alpha = F \cos\alpha\,\mu$

$\frac{\tan\alpha}{\cos\alpha} = \mu$

METALS ON METALS DRY .15 – .20
WET

SMOOTH SURFACE [illegible] .05

③

[illegible] .05

$\frac{\tan\alpha}{\cos\alpha} = .05$

TRY 5°

$\frac{.087}{.996} = .09 > .05$ SLIPPING WILL OCCUR

TRY 1°

$\frac{.0175}{.999} = .017 < .05$

TRY 3°

$\frac{.05241}{.998} = .05 = .05$

3° IS LARGEST PERMISSIBLE ANGLE

④

$l = .712$

TORQUE POSSIBLE TO APPLY TO CONNECTOR = 12 IN#

$F\,l = 12$ IN#

$F = \frac{12}{.712} = 17$#

$N = \frac{F}{\tan\alpha} = \frac{17}{.05} = 340$#

FORCE HOLDING FLANGE TOGETHER = 2N = 680# !

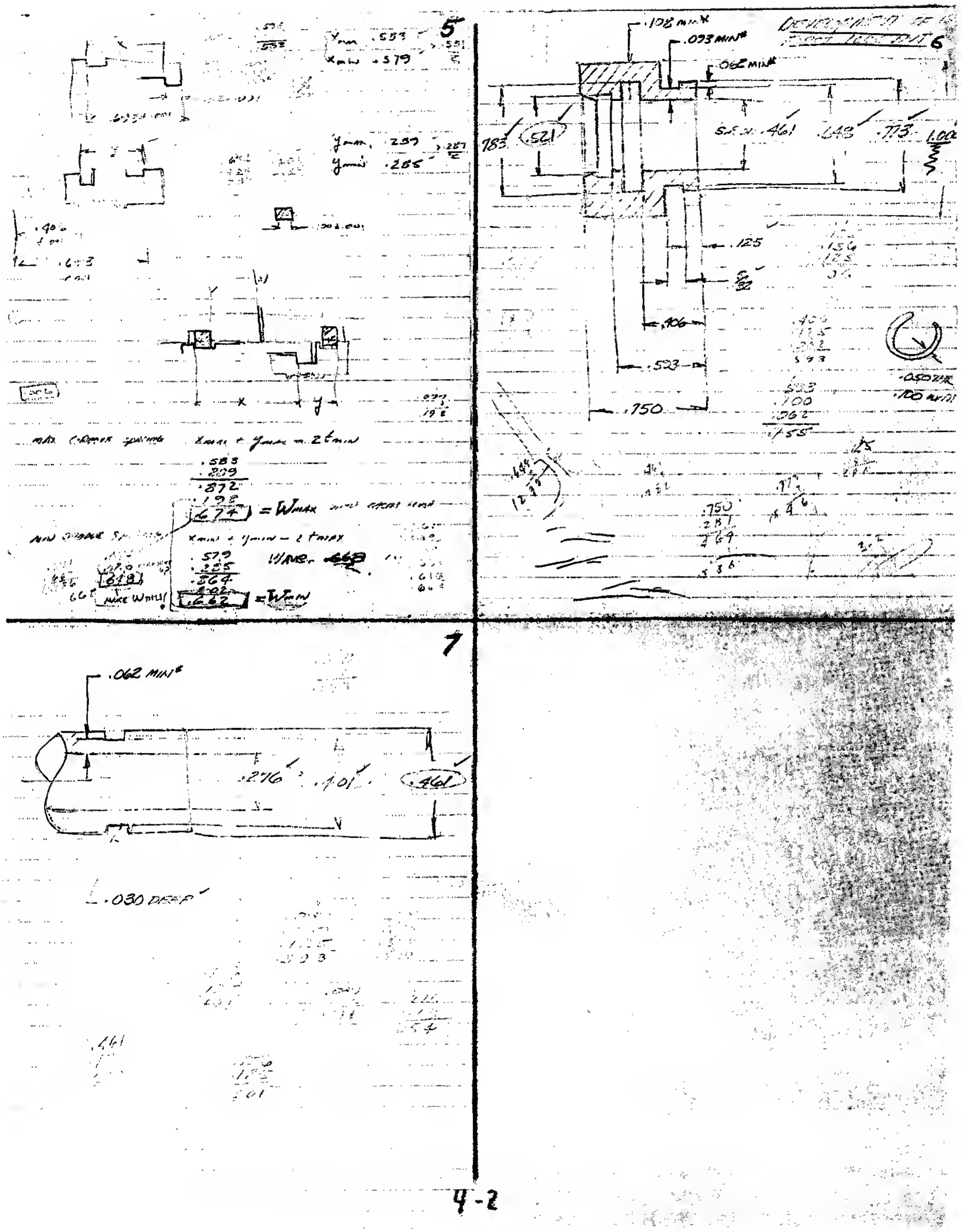


Exhibit 5B

Nut

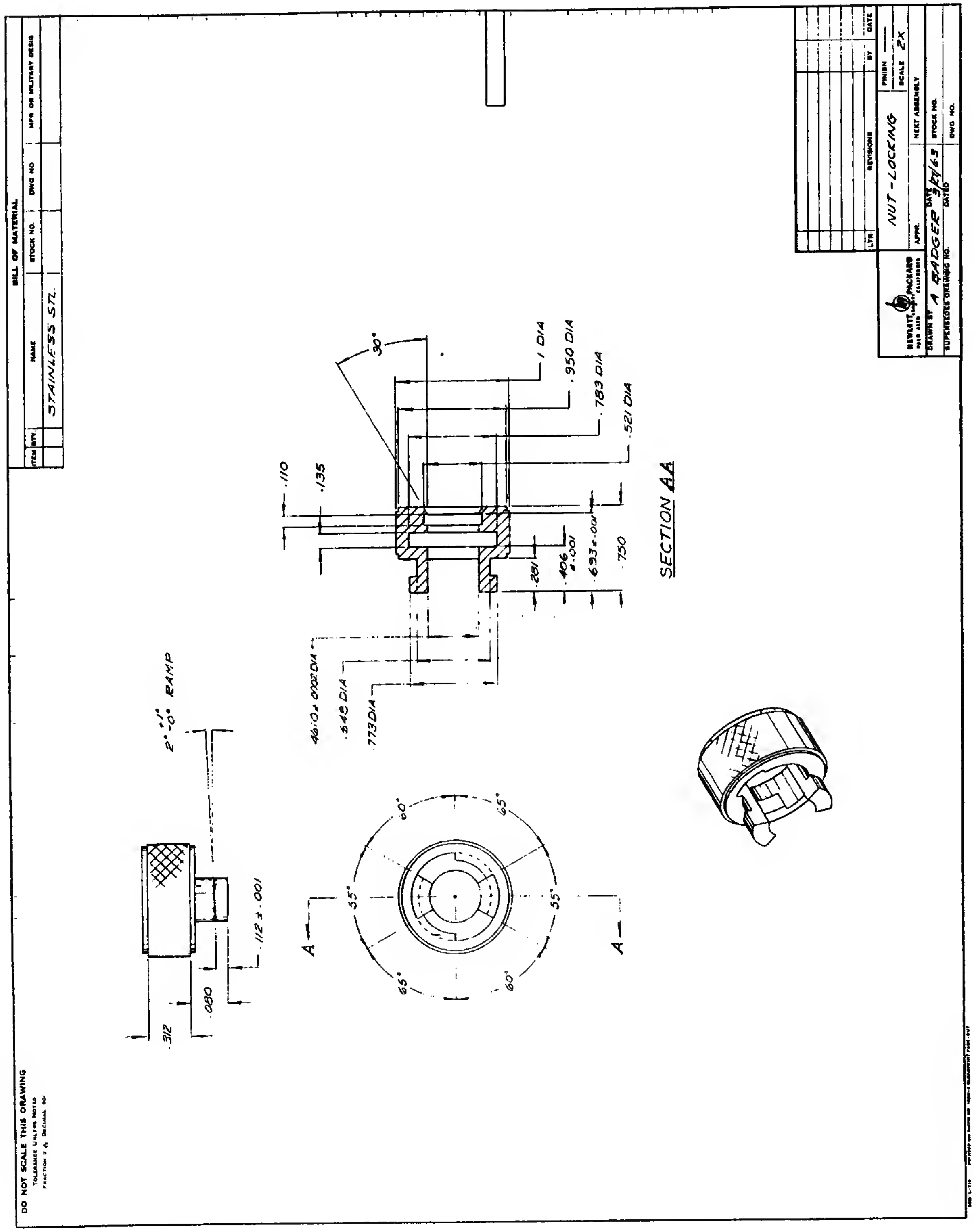


Exhibit B6

ECL 1B

Mounted Nut

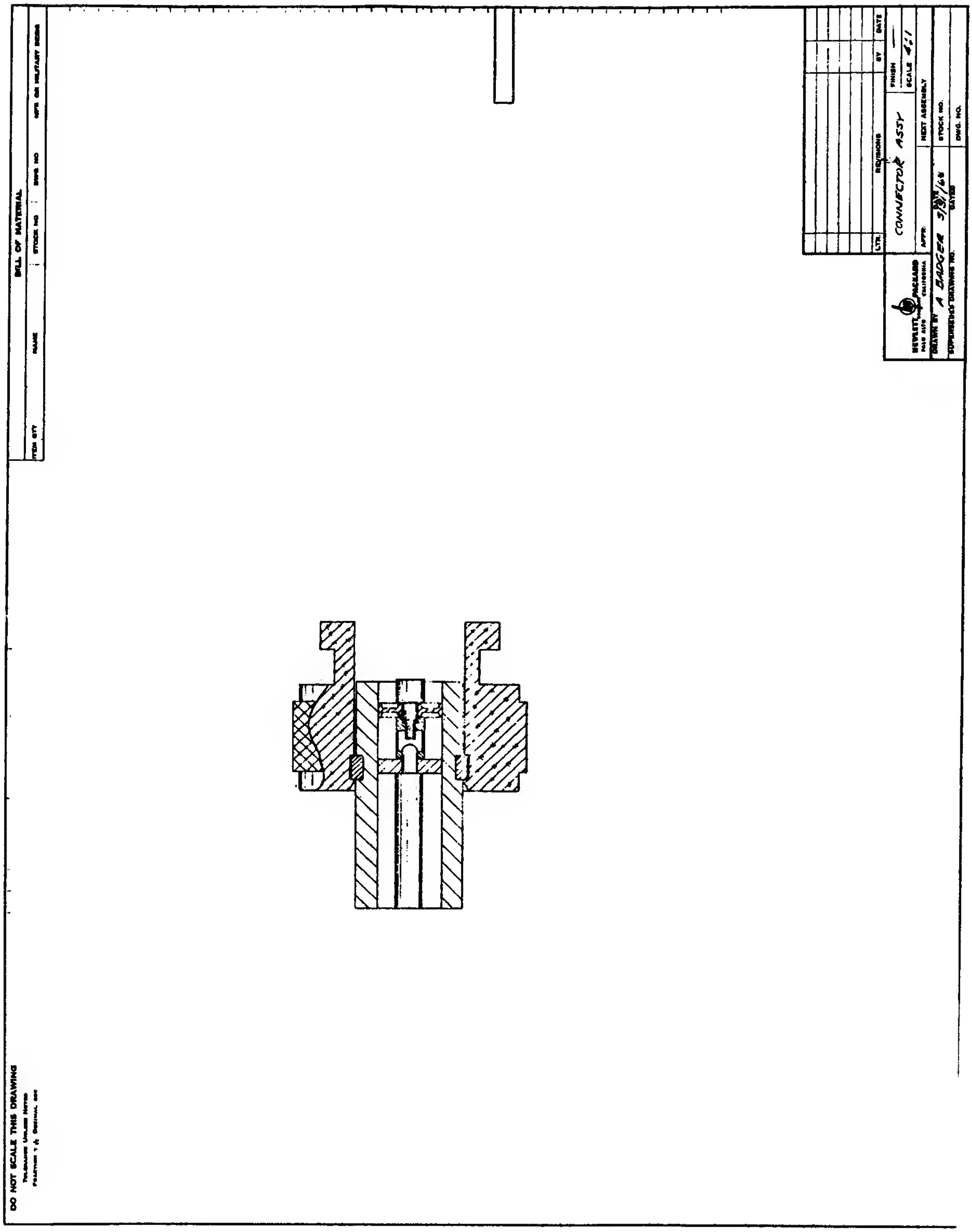
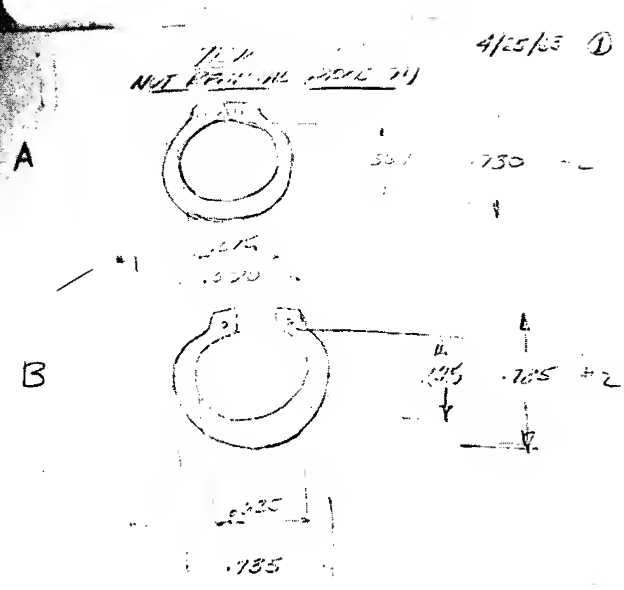


Exhibit B7a

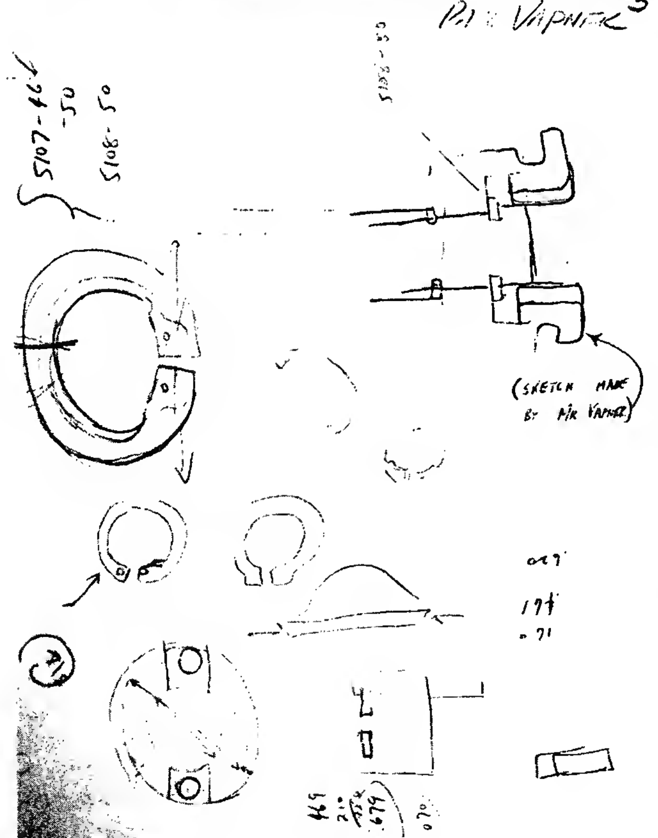
Mounting Design

4/25/63 ①



	DIA #1		DIA #2	
CASE B	.625	.735	.625	.735
CASE A	.575	.690	.567	.730
DIFF	.050	.045	.058	.055

Re: Vapnik 3



4/25/63 ②

1.) SET SCREW IN GROOVE
2.) SNAP RING - WIRE ~~DRAWN~~] A POSSIBILITY
3.) TRUARC
4.) SCREW
5.) CLAMP
~~6.) BALL AND ROLLER STOP~~
7.) SPRING LOAD
8.) SWIVEL
9.) INTERLOCKING TANGS
11.) GROOVE & KEY
10.) SHANK
12.) TAPER
13.) SHOULDER
14.) TEFLON - PLASTIC
15.) SPRING LOADED PLUG
16.) ROLLERS
17.) COIL SPRING
18.) SPLIT MALE & FEMALE
19.) DETENT, SNAP, QUICK RELEASE

CENTER CONDUCTOR MECHANISM

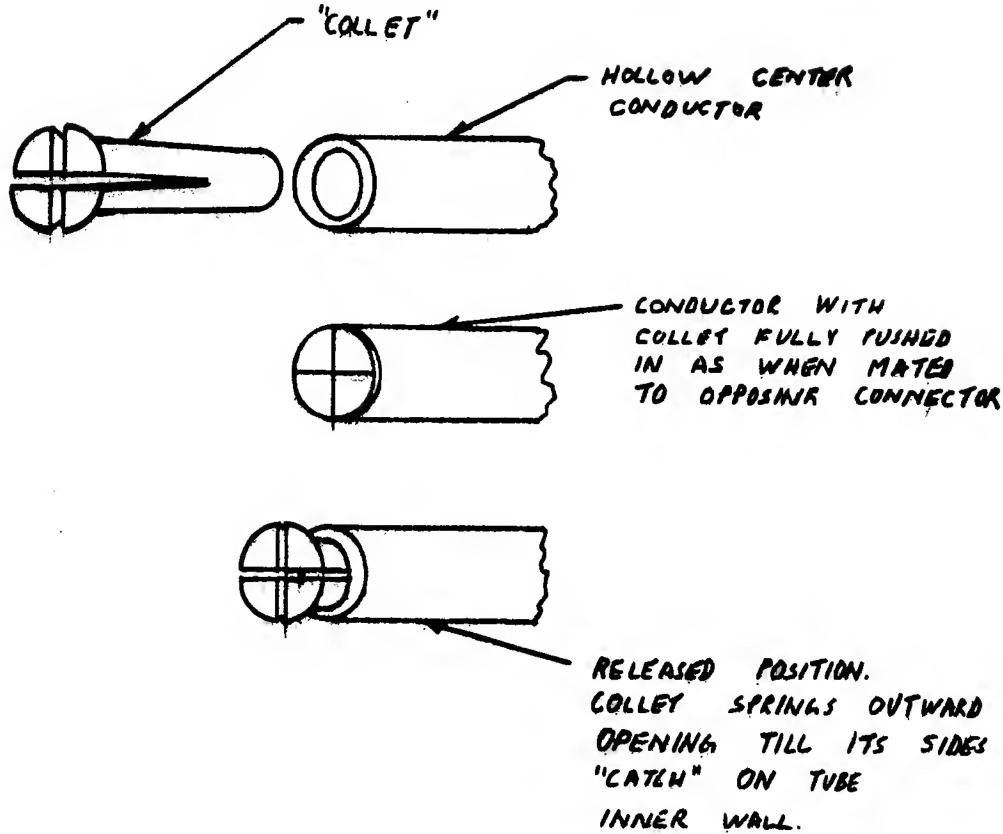


Exhibit B8 Bid Request ECL 1B

HEWLETT-PACKARD COMPANY

Laboratory Instruments for Speed and Accuracy

1501 PAGE MILL ROAD, PALO ALTO, CALIFORNIA

AREA CODE 415 - PHONE 326-7000

December 5, 1963

Mr. Bill Chatelain
Swiss Automatic
3551 San Thomas
Santa Clara, California

Dear Mr. Chatlain:

Enclosed are drawings of eight parts that we would like quotes on. In several instances, it will be noticed that a part will leave several different combinations of tolerances. We would like quotes on each of these individual cases.

In each case, we would like quotes for volumes of 1000, 5000, 10,000 parts. In cases where stainless steel is specified as the material, we would be interested in what reduction in part cost would result in substituting phos. bronze for stainless.

The production of these parts is estimated at a minimum of 25,000 yearly for each individual part.

Sincerely,

Hewlett-Packard Company

Anthony S. Badger
Microwave Division

ASB:ga

Enclosure

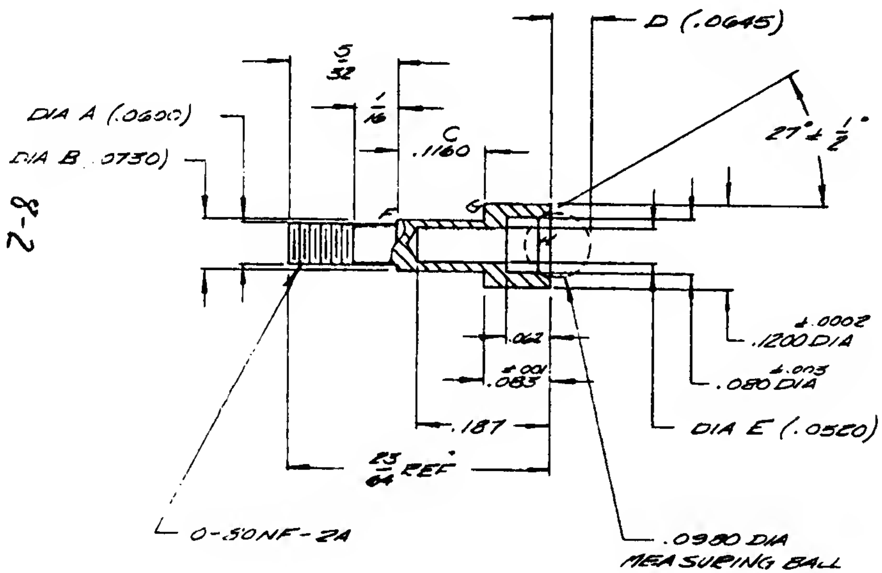
C O P Y

DO NOT SCALE THIS DRAWING

			BILL OF MATERIAL		
ITEM	QTY.	NAME	STOCK NO.	DWG. NO.	MFR. OR MILITARY DESIG.
		303C STAINLESS			

NOTE:

1) SURFACE RUNOUT REL ℄ A
   F .0002 T.I.R
   G .0005 T.I.R
2) H MUST BE CONCENTRIC REL ℄ DIA E TO .0005 T.I.R.



CASE I

DIMEN	TOL	RUNOUT REF ℄ A
A	±.0005	ZERO
B	±.0005	.0005 T.I.R
C	±.0005	NOTE
D	±.002	NOTE
E	±.0005	.004 T.I.R

CASE II

DIMEN	TOL	RUNOUT REF ℄ A
A	±.0002	ZERO
B	±.0005	.0005 T.I.R
C	±.0005	NOTE
D	±.002	NOTE
E	±.0005	.004 T.I.R

CASE III

DIMEN	TOL	RUNOUT REF ℄ A
A	±.0002	ZERO
B	±.0002	.0005 T.I.R
C	±.0002	NOTE
D	±.002	NOTE
E	±.0005	.004 T.I.R

CASE IV

DIMEN	TOL	RUNOUT REF ℄ A
A	±.0002	ZERO
B	±.0002	.0005 T.I.R
C	±.0002	NOTE
D	±.001	NOTE
E	±.0005	.004 T.I.R

CASE V

DIMEN	TOL	RUNOUT REF ℄ A
A	±.0002	ZERO
B	±.0002	.0005 T.I.R
C	±.0002	NOTE
D	±.001	NOTE
E	±.0002	.004 T.I.R

C-5020-02551-

CASE VI

DIMEN	TOL	RUNOUT REF ℄ A
A	±.0002	ZERO
B	±.0002	.0005 T.I.R
C	±.0002	NOTE
D	±.001	NOTE
E	±.0002	.004 T.I.R

LTR.	REVISIONS	BY / DATE

HEWLETT PACKARD

HOLDER-COLLET

SCALE 4:1

DRAWN BY A BADGER 12/2/65

STOCK NO. 5020-025

DWG. NO. C-5020-025

8-2

SWISS AUTOMATIC PRODUCTS

551 Thomas Road Phone 243-3500 Santa Clara, Calif.

High Precision
Screw Machine Products
From 1/64" to 1/2"

QUOTATION

Hewlett Packard Co.
1501 Page Mill Rd.
Palo Alto Calif.

1-2-64.

Dear Mr.A.Badger,

We are thanking you for the opportunity to quote on the following jobs.

Parts # C-5020-02351-1-1 (COLLET HOLDER)

	Case #1	Case # 2	Case #3	Case #4	Case #5	Case #6
1M	.57ea	.59ea	.595ea	.61ea	.65ea	.65ea.
5M	.55ea	.57ea	.575ea	.59 ea	.63ea	.63ea.
10M	.53ea	.55ea	.56 ea	.57ea	.61ea	.61ea.

Parts # C-5020-02350-1-1 (BEAD)

	Case #1	Case #2	Case #3	Case #4
1M	.22ea	.26ea	.26ea	.31ea.
5M	.18ea	.23ea	.23ea	.28ea.
10M	.15ea	.21ea	.21ea	.26ea.

Parts # C-5020-0252-1-1 (COLLET)

	Case #1	Case #2	Case #3	Case*
1M	.71ea	.75ea	.81ea.	
5M	.68ea	.72ea	.78ea.	
10M	.66ea	.70ea	.76ea.	

Parts # B-5020-0253-1-1 (CUP)
1M Pces at .91ea. 5M Pces at .88ea. 10M Pces at .85ea.
Parts # B-5020-0254-1-1 (CUP HOLDER STR SHANK)
1M Pces at .35ea 5M Pces at .32ea. 10M Pces at .28ea.
Parts # B-11526-200-1-2 (C COND NIPPLE)
1M Pces at .76ea 5M Pces at .73ea. 10M Pces at .71ea.
Parts # B-11524A-200-1-2 (C COND - [illegible])
1M Pces at .93ea 5M Pces at .91ea. 10M Pces at...88ea.
Parts # B-5020-0255-1-1 (COLLET HOLDER STR SHANK)
1M Pces at .46ea 5M Pces at .43ea. 10M Pces at .40ea.
Tooling at 50.00 per set of Cams for each Item.

We Hope this prices will meet your approval.

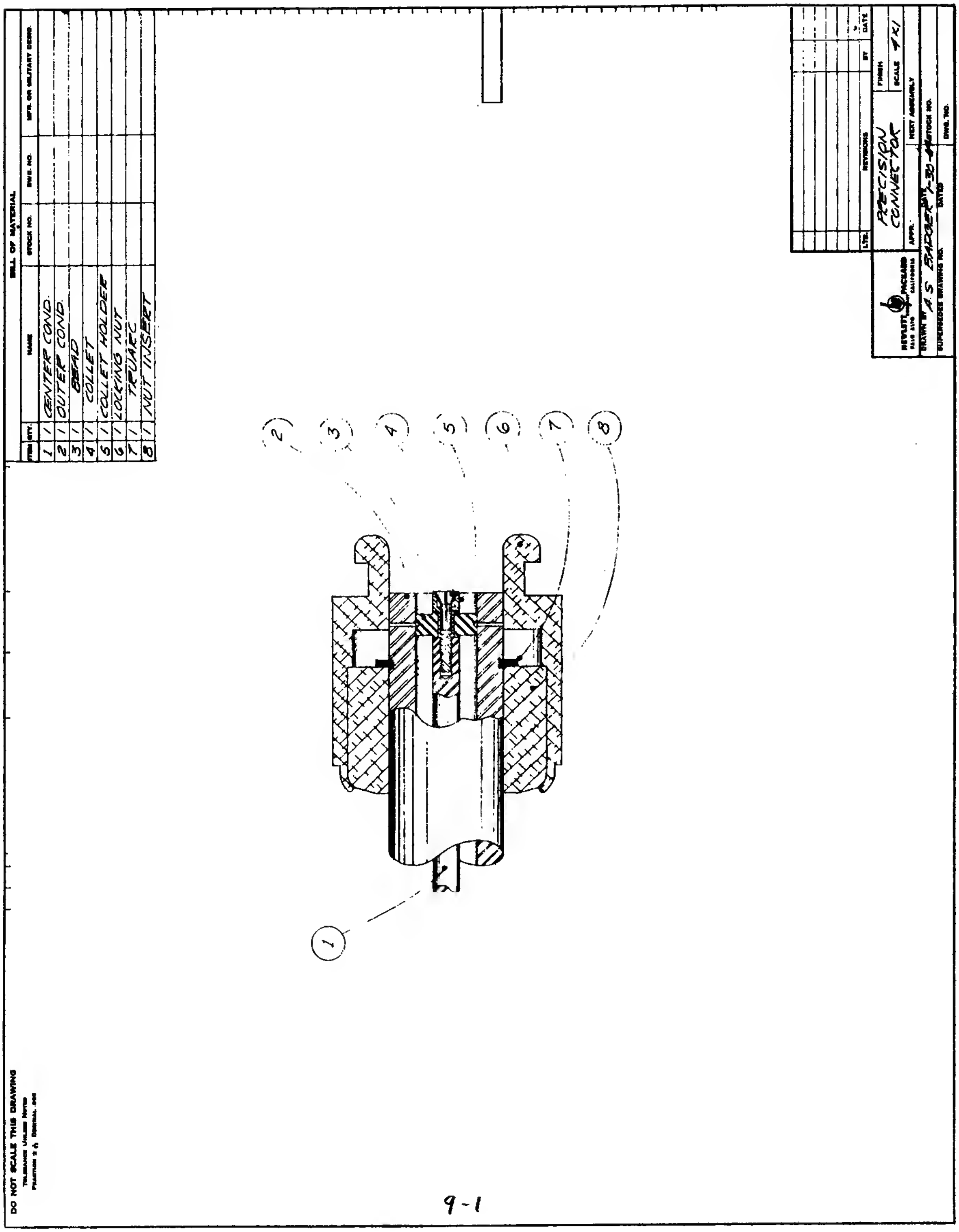
Thanking You,

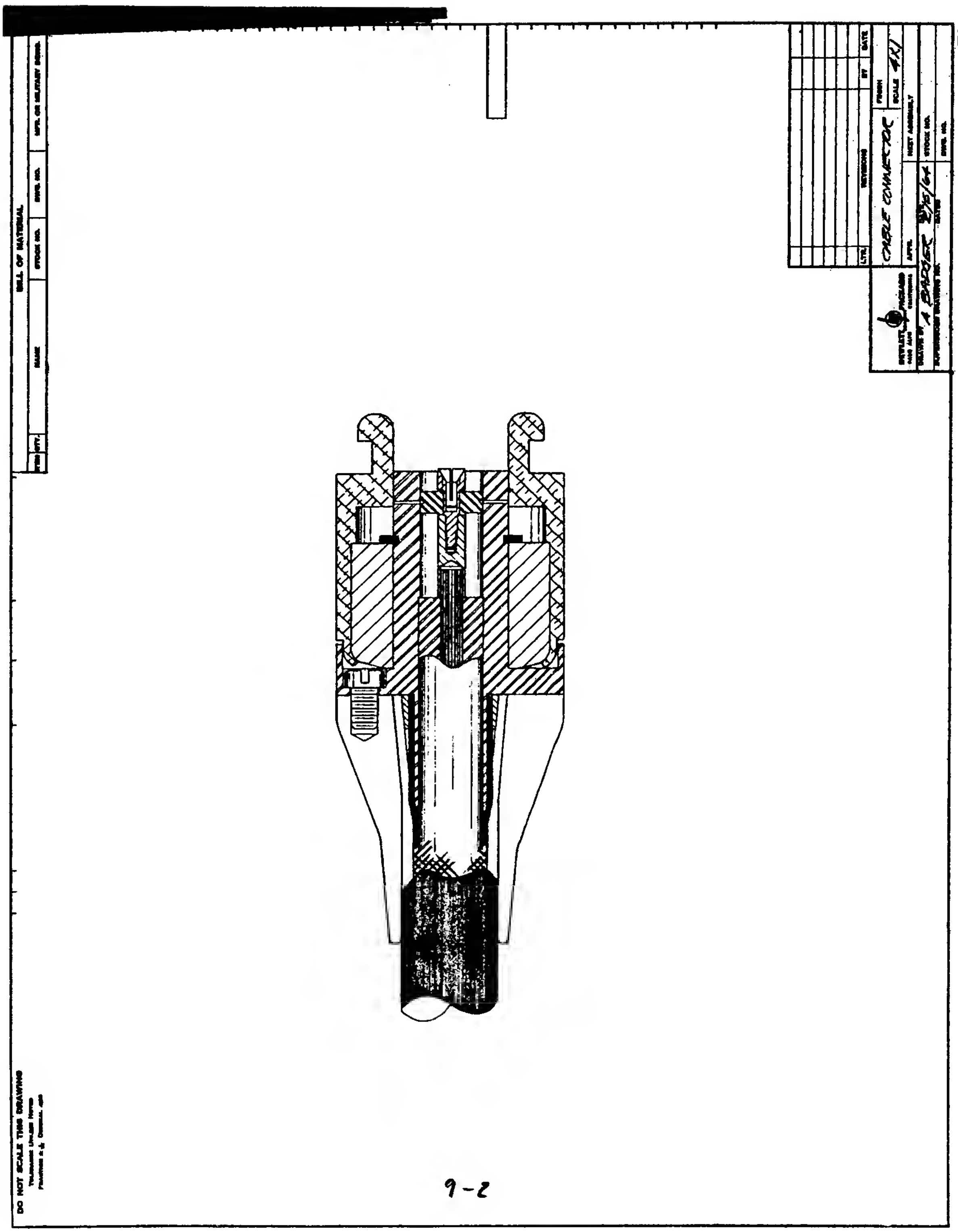
Wm. Chatelain

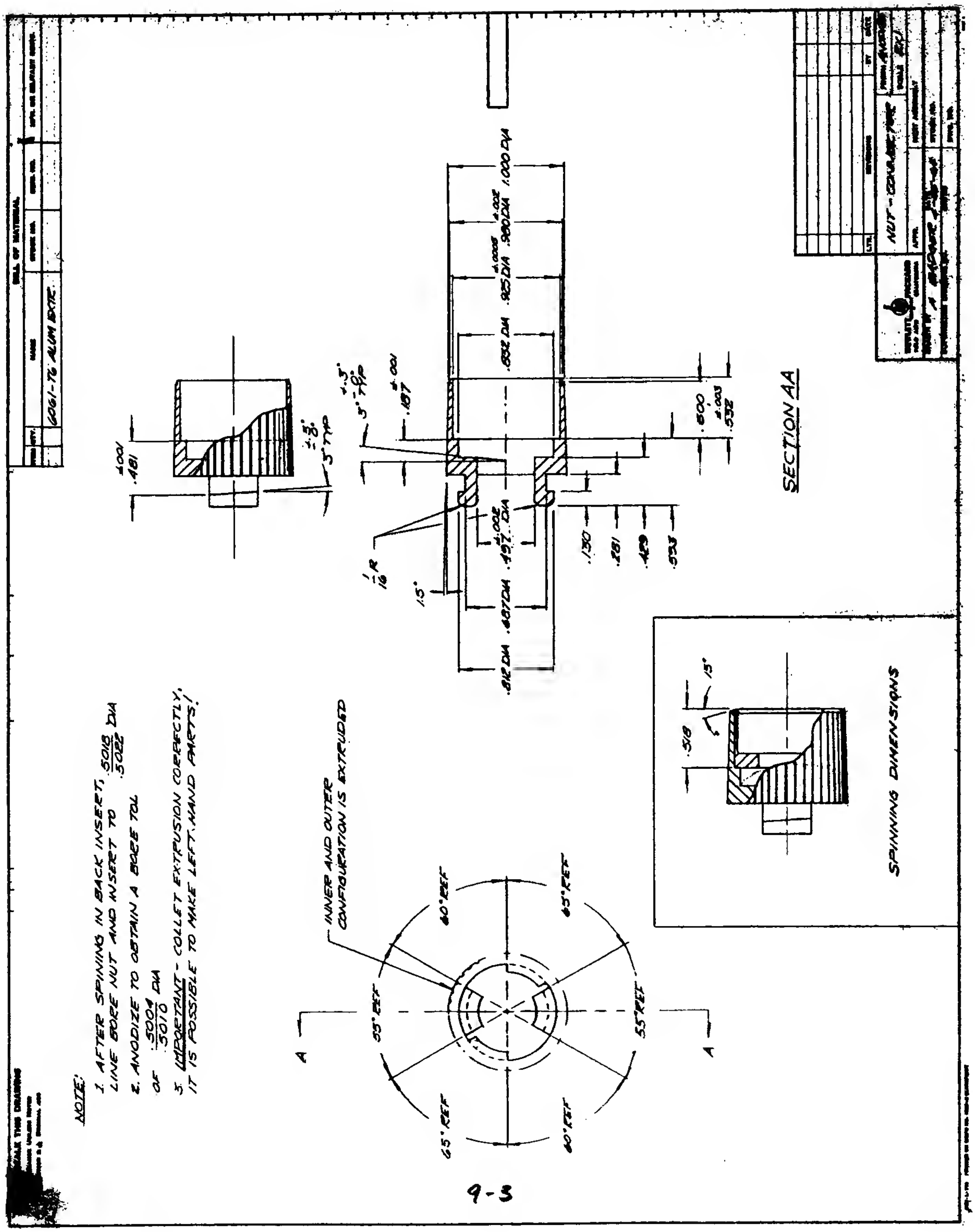
Wm.Chatelain

Exhibit B9

Connector Assembly



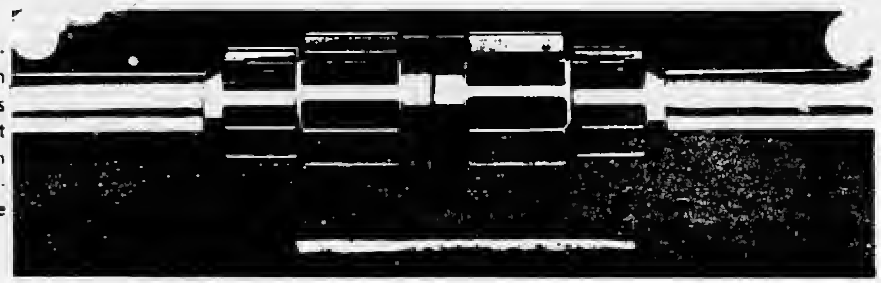

BILL OF MATERIAL
CABLE CONNECTOR
DO NOT SCALE THIS DRAWING


NOTE:
1. AFTER SPINNING IN BACK INSERT, LINE BORE NUT AND INSERT TO .5018/.5022 DIA
2. ANODIZE TO OBTAIN A BORE TOL OF .5004/.5010 DIA
3. IMPORTANT - COLLET EXTRUSION CORRECTLY, IT IS POSSIBLE TO MAKE LEFT HAND PARTS!
INNER AND OUTER CONFIGURATION IS EXTRUDED
SECTION AA
SPINNING DIMENSIONS
6061-T6 ALUM EXTR.
NUT-CONNECTOR
9-3

EXCERPTS FROM NEW CONNECTOR ADVERTISEMENT
(Courtesy Amphenol-Borg Electronics Corporation)

The devek. .ent of Amphenol Precision Coaxial Connectors extends the application of coaxial techniques to 18 Gc. These new connectors combine the inherent advantages of coaxial devices — broad band characteristics, mechanical flexibility, low cost — with electrical efficiencies previously available only wi. veguide.

This new line of connectors is the result of a joint effort by Hewlett-Packard Company and Amphenol-Borg Electronics Corporation. Original design was undertaken by Hewlett-Packard. Patent rights have been purchased by Amphenol. Product development and associated testing have been conducted on a cooperative basis by the two companies. The connectors are manufactured at the Danbury plant of Amphenol-Borg.



PRECISION COAXIAL CONNECTORS

Amphenol INFORMATION BULLETIN | GP-7

Performance standards are derived from specifications of the Subcommittee on Precision Coaxial Connectors of the Technical Committee on Electronic and High Frequency Instruments, IEEE.

The Amphenol line embraces three major categories of connectors in the 7 mm class. The GPC-7 (general precision connector) meets or betters specifications of the Subcommittee. Data shown in this bulletin pertains to the GPC-7 Series.

Specifications have not yet been completed by the Subcommittee for the LPC-7 Series (laboratory precision connectors). When these are announced, Amphenol will provide an LPC-7 Series in full compliance.

The LPC-7 connector will be similar to the GPC-7 except for the elimination of the supporting dielectric.

Specifications applicable to the FPC-7 Series (field precision connector) vary according to application. Amphenol engineers will assist customers to adapt this connector to specific needs.

FEATURES

QUICK-CONNECT COUPLINGS

Mating is accomplished by means of an inclined plane quick-connect coupling nut. A positive connect is made with only a quick twist of the fingers.

This method of coupling contrasts with other precision connectors which use separate parts for alignment and coupling. The single precision component employed in the GPC-7 for both functions assures precise, repeatable alignment over hundreds of mating cycles.

SEXLESS

Amphenol Precision Coaxial Connectors are sexless. This means they will mate with any other Amphenol precision connector without an electrical or mechanical adapter. Efficiency, economy and convenience result.

CAPTIVATED COMPONENTS

All components are captivated to assure repeatability, minimum wear, minimum discontinuity and to reduce the chance of misplaced parts.

BROAD-BAND COVERAGE

Amphenol Preci: oaxial Connectors may be used with a high degree of rical efficiency at any frequency to

LOW STANDING WAVE RATIO

VSWR is in strict conformance with the requirements of the Subcommittee on Precision Coaxial Connectors. For each mated pair purchased, Amphenol will certify that the pair meets or betters the Subcommittee value of 1.003 +0.002 f (Gc).

This excellent performance is the result of careful design and the extremely close mechanical tolerances on all components. Coaxial concentricity of a mated pair is assured by the unique method of coupling in which the butt joint outer contacts are drawn into precise alignment. The inner conductors are spring loaded so that coupling compresses them into concentric alignment with the outer conductors.

Those connector cross sections affecting electrical characteristics present no discontinuity. The slight effect of the dielectric support is virtually nullified by compensating design.

LOW RF LEAKAGE

RF leakage is at least 120 db below signal level. This is attained by machining the contacting surfaces within 0.0005 inch of square and by means of the compressive action of the coupling mechanism.

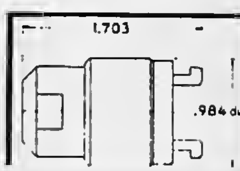
BROAD LINE AVAILABILITY

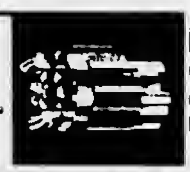
The GPC-7 Series is designed for use with 7 mm rigid air lines. Prototype quantities are available from stock effective October 1, 1964. Associated rigid line and tool kits are similarly available.

Some systems applications require a smaller diameter coupling mechanism. The design of GPC-7 permits simple field replacement of the standard coupling with a threaded coupling nut with diameter less than ¾". This CONVERTOR feature is another example of the design flexibility available for systems applications. Prototype quantities will be available concurrent with the basic GPC-7 connector.

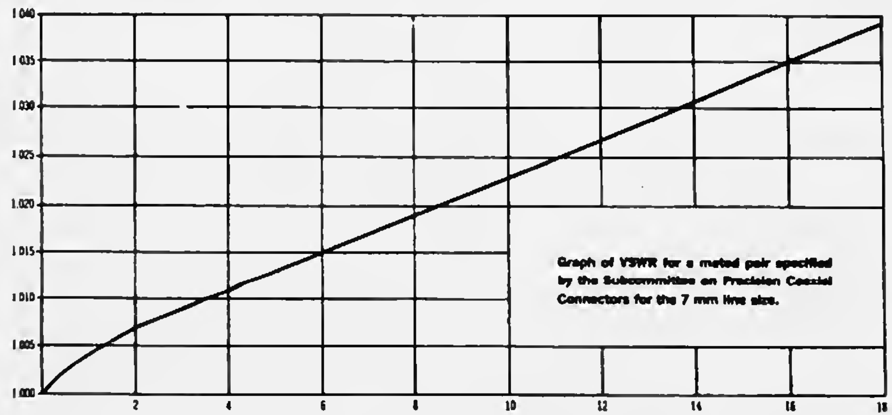
Adapters to common connector series will be available from stock in the near future.

Designs for attachment to semi-rigid and flexible cable are nearing completion and will be announced.





The Amphenol GPC-7 Precision Coaxial Connector meets all requirements of the Subcommittee. The most important of these specifications are included below:



G-1

Amphenol will provide a certified test report with each mated pair ordered showing compliance with the Subcommittee's requirement on VSWR.

INPUT IMPEDANCE	50 ohms
FREQUENCY RANGE	0 - 18 Gc.
TEMPERATURE RANGE	−55°C to 70°C
CONTACT RESISTANCE OF MATED PAIR	
Inner Conductor	less than 5.0 milliohms
Outer Conductor	less than 0.5 milliohms
INSULATION RESISTANCE	greater than 5 x 10¹¹ ohms
BREAKDOWN VOLTAGE	4.0 KV (DC)
RF LEAKAGE	120 db below signal level
INSERTION LOSS	less than .01 $\sqrt{f}$ Gc per pair

MANUFACTURED BY

...ES

Connectors	Unit Price
GPC-7 General Precision Connector	$35.00
FPC-7 Field Precision Connector (exact price depends upon specific application)	$15.00-$20.00
7 MM Precision Air Line Assemblies (Fitted with one GPC-7 each end)	
GPC-7-L5 5 cm line length	$80.00
GPC-7-L10 10 cm line length	$85.00
GPC-7-L15 15 cm line length	$90.00
7 MM Precision Air Line Components	
GPC-7-IC Precision Inner Conductor	$10.00/ running foot
GPC-7-OC Precision Outer Conductor	$13.95/ running foot

Prices on conductors apply to 2-foot lengths. Inner and outer conductors can be supplied machined for immediate assembly to a GPC-7 connector. The price of this operation is $6.00 per end.

Accessory Tool Kit	
GPC-7-TK Assembly tool kit, includes necessary tools for assembly of the GPC-7 to a precision	$2[illegible]

Hewlett-Packard Company (C)

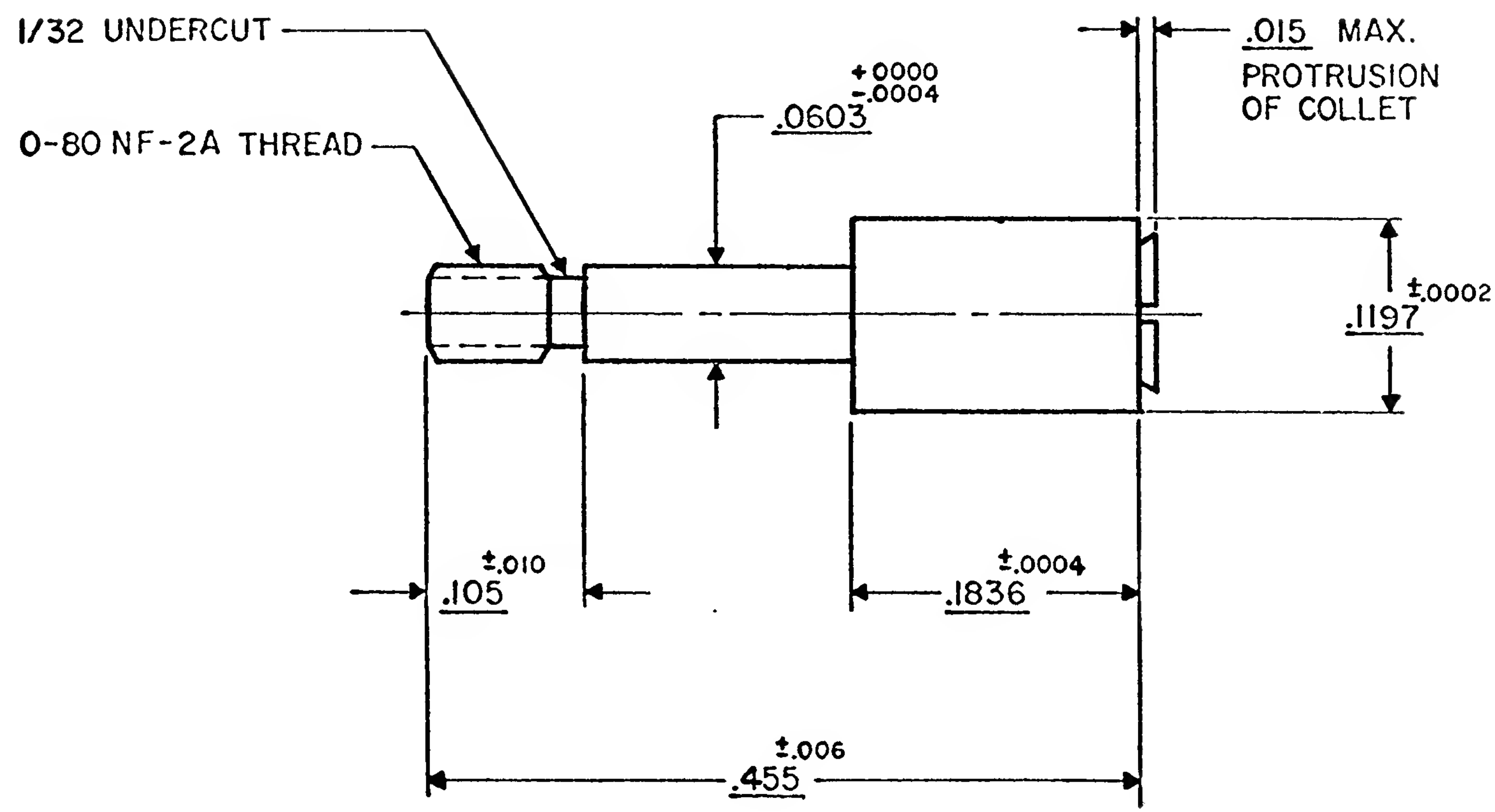
Hewlett-Packard Company/Amphenol Corporation
Commercial Development of the Sexless Connector

Mr. Badger of Hewlett-Packard applied for a patent covering a sexless connector in February, 1964 (this patent is shown in Exhibit C1). During the following month Hewlett-Packard produced about 1,000 of these connectors and used them in their own laboratory for evaluation and microwave product developments.

Amphenol Corporation, during approximately the same time span, was developing on its own various designs of sexless precision connectors with particular emphasis being placed on a broadband dielectric support structure operable to 18 GHz.

In August 1964, the Amphenol Corporation purchased the patent rights for the Badger connector and launched a thorough study of the problems that might be encountered with the coupling mechanism employed in the Badger design. Particular consideration was given to the fact that the design had to be mass producible and the coupling mechanism reliable under all application conditions.

Prepared in the Design Division, Department of Mechanical Engineering by Sue E. Hayes. The assistance of Mr. Anthony Badger of the Hewlett-Packard Company and of Mr. R. P. Avery and Mr. T. N. Anderson of the Amphenol Corporation is gratefully acknowledged.



ALL DIMENSIONS IN INCHES

CONTACT FOR AMPHENOL 7MM PRECISION CONNECTOR

AMPHENOL DWG No. 693-159

United States Patent Office

3,245,028

Patented Apr. 5, 1966

1

3,245,028

CONNECTORS

Anthony S. Badger, Palo Alto, Calif., assignor, by mesne assignments, to Amphenol Corporation, a corporation of Delaware

Filed Feb. 17, 1964, Ser. No. 345,218

4 Claims. (Cl. 339—90)

This invention relates to sexless connectors for cylindrical pipes or lines such as electrical coaxial transmission lines.

Terminal connectors of male and female types have been in common use for joining the ends of tubular members such as coaxial transmission lines in electrical apparatus. Considerably difficulty and inconvenience are frequently encountered, however, in using connectors of this type because of the necessity of mating male and female ends of the members to be joined.

Accordingly it is an object of the present invention to provide a sexless connector for tubular or coaxial members.

It is another object of the present invention to provide a sexless connector which is quickly connected and disconnected without the aid of tools and which has high mechanical rigidity and strength.

It is also an object of the present invention to provide a sexless connector which locks the members to be joined in accurate axial alignment.

It is still another object of the present invention to provide an improved sexless connector.

In accordance with the illustrated embodiment of the present invention, a rotatable barrel is held in fixed axial position near the planar end of each of the members to be joined. These barrels are identical and include a pair of protruding prongs having inclined locking tapers which engage radial surfaces in the mating barrels. Opposite rotation of the barrels produces an axial engaging force on the members to be joined. Surfaces of the protruding prongs are referenced against cylindrical surfaces of the mating barrels to provide coaxial alignment of the members to be joined. The members to be joined may be locked together in any relative angular position about the common axis of alignment.

Other and incidental objects of the present invention will be apparent from a reading of this specification and an inspection of the accompanying drawing in which:

FIGURE 1 is a sectional view of an assembled connector according to the present invention, and

FIGURE 2 is a perspective view of the connector in accordance with the present invention.

Referring to FIGURES 1 and 2, there is shown a pair of tubular members **9**, **11** such as the outer conductors of a coaxial line which are to be joined together. Each of the members carries a barrel **13**, **15** which is rotatable about the respective member but which is fixed thereon in an axial position near the end **17**, **19** of the member by a snap ring **21**, **23** on one side and by a shoulder **25**, **27** on the other side. The barrels **13**, **15** are identical and each includes a diametrically-opposed pair of prongs (only prongs **29**, **31** on barrel **13** appear in the sectional view of FIGURE 1) which project axially beyond the ends **17**, **19** of the members to be joined. These prongs pass axially through regions of large diameter in the front portions of the mating barrels as the members to be joined are brought together. The inner cylindrical surfaces **32** of the prongs provide axial alignment for the members **9**, **11** as they are brought together. A helically-tapered radial surface **33** on each of the prongs engages a radial surface on the inside of a mating barrel in a region thereof where the front portion is of reduced diameter. Relatively opposite rotation of the barrels **13**, **15** (or rotation of one barrel only) produces an axial engaging force

2

which urges the ends **17**, **19** of the members **9**, **11** together. A suitable resilient O-ring gasket **35** of such composition as silver-plated tiny copper balls in potting resin is disposed within the annular groove **37** in the mating ends **17**, **19** of the members to be joined for decreasing leakage of electrical signal through the joint.

In the illustrated embodiment of the invention, member **11** is attached to a flexible line such as a coaxial cable **39** and member **9** is part of a rigid fixture such as the output terminal of a signal source. The cable **39** includes a wound-strand center conductor **41** which is held in coaxial alignment with the outer shield conductor **43** by dielectric material **45**.

The outer shield **43** is held in electrical contact with the member **11** by the jam-tapered ring **51** which is split longitudinally and which is disposed between the shield **43** and the outer insulating layer **53** of the cable **39**. The mating tapered aperture **55** in the housing **57** imparts force through the outer layer **53** to the ring **51** which thereby tightens the shield conductor **43** around member **11** as the housing **57** is pulled axially against the shoulder **27** of the member **11** by the bolts **59**. This clamps the cable **39** rigidly to the member **11** and forms a fluid-tight seal having high tensile strength.

The center conductor **47** of the member **9** is held in coaxial alignment with the outer conductor by dielectric material **49**. Each of the center conductors **41**, **47** is connected to a conductive element **61**, **63** as by soldering or crimping. A collet holder **65**, **67** passes through a dielectric spacer **69**, **71** and screws into the element **61**, **63**, thereby aligning the element and holding it axially and radially rigid within the member **9**, **11**. Resinous potting compound is injected through holes **73**, **75** into the grooves **77**, **79** about the spacers **69**, **71** to hold them in place. A collet **81**, **83** having a tapered end region and having a plurality of intersecting axial splits is slidably mounted in the collet holder. The tapered end regions on each of the split collets acts against the edge of the collet holder to impart axial motion to the collet as the collet finger expands resiliently outward. This urges the collets together to make good electrical contact between center conductors of the lines to be joined. The outer dimension of the collets and the inner dimension of the aperture in the collet holders are so chosen that the collet fingers expand sufficiently to engage the walls of the apertures when the sections of the connector are disconnected, thereby preventing the collet from falling out of the holder.

I claim:

1. In a connector for joining conductors, contact means for a conductor in one section of said connector comprising:

an element connected to said conductor and having a longitudinally cylindrical bore therein;

a member slidably disposed within the bore of said element, the member having a longitudinal split along a portion of the length thereof for providing diametrical expansion of said member; and

means on said member responsive to diametrical expansion thereof for urging said member outwardly from said bore.

2. In a connector for joining conductors, contact means for a conductor in one section of said connector comprising:

an element connected to said conductor and having a longitudinally cylindrical bore therein;

a cylindrical member of resiliently expandable diameter slidably disposed within the bore of said element; and

a tapered surface on said member disposed to engage an end of the cylindrical bore for urging s[illegible] member outwardly from said bore in response to [illegible]metrical expansion of said member.

3. Contact means as in claim 2 wherein the diameter of the cylindrical bore in said element is smaller than the maximally expanded diameter of said member for impeding further outward-sliding motion of said member within said bore by engagement of the inner surface of the cylindrical bore and an outer surface of the expanded member after a predetermined amount of axial movement of said member outwardly from said bore.

4. A sexless connector for joining a pair of members and comprising for each of said members:

a barrel rotatably mounted on the member;

a plurality of prongs on the front portion of the barrel protruding axially beyond the end of said member; and

a helically-tapered radial surface on each of said prongs for engaging a radial surface of a mating barrel whereby relative rotation of the barrels imparts an axial engaging force upon the ends of said members;

at least one of said members having

an element disposed coaxially within said member about the longitudinal axis thereof;

said element having a longitudinal aperture therein;

and resilient means disposed within said aperture having an end protruding beyond the end of said element;

said resilient means includes a collet having a longitudinal split along a portion of the length thereof and having at least one tapered end;

said tapered end varying in diameter between values larger and smaller than the diameter of the aperture in said element and being disposed to engage an end of said apertures in the element.

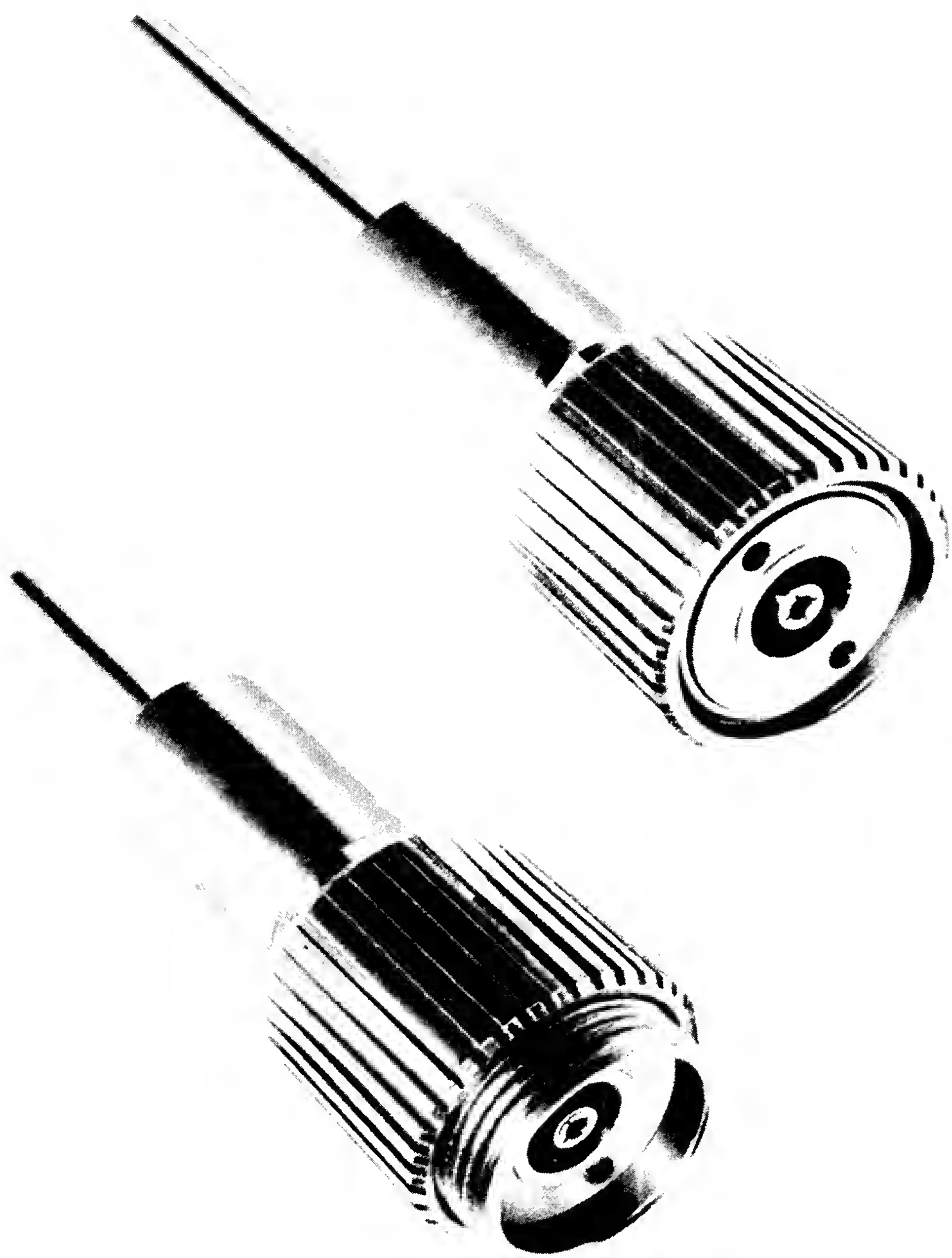
References Cited by the Examiner

UNITED STATES PATENTS

2,171,726	9/1939	Howell	339—47
3,040,288	6/1962	Edlen et al.	339—117 X
3,129,993	4/1964	Ross	339—49

PATRICK A. CLIFFORD, *Primary Examiner.*

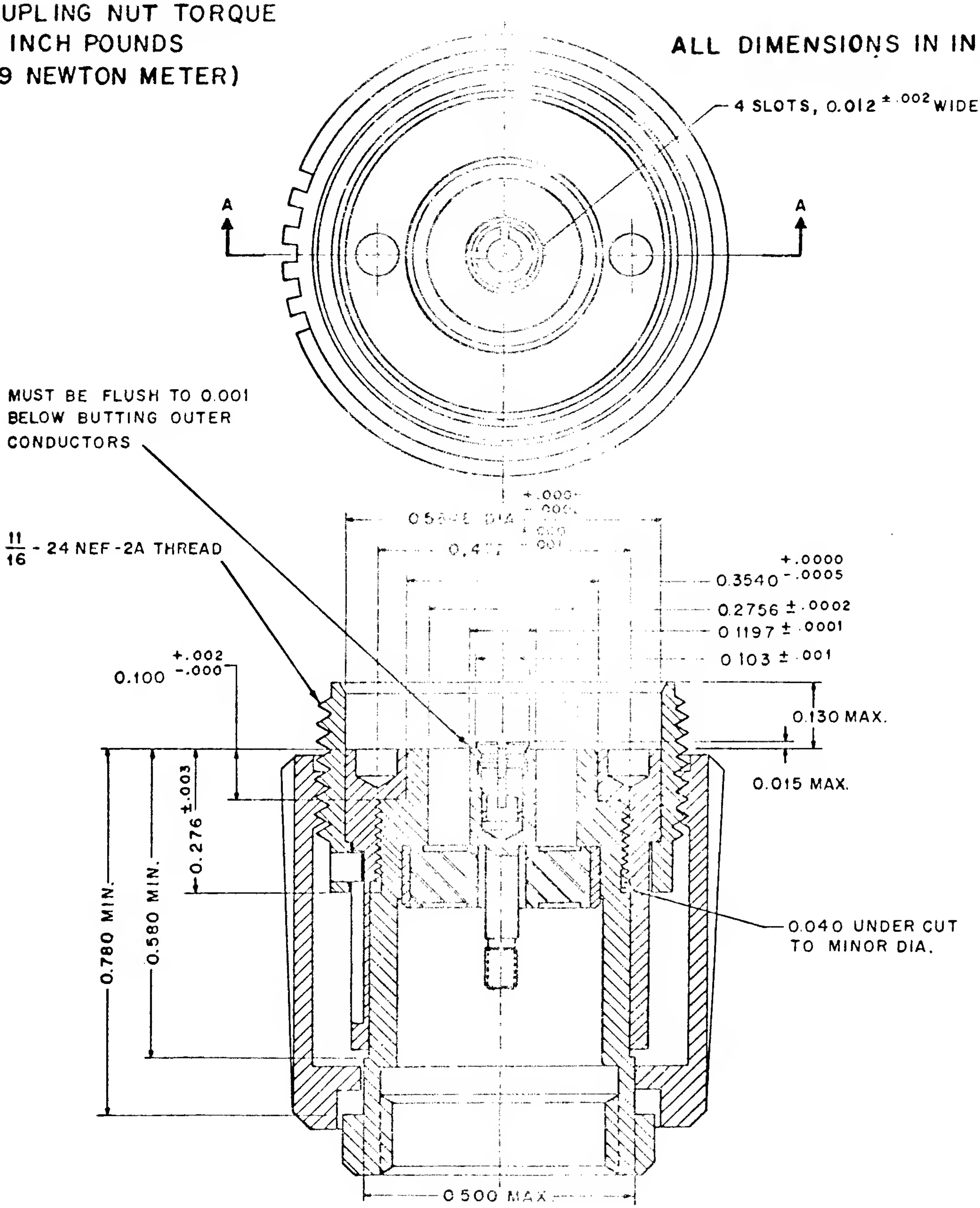
W. DONALD MILLER, *Examiner.*



Amphenol Precision 7mm Connector

COUPLING NUT TORQUE
8 INCH POUNDS
(0.9 NEWTON METER)

ALL DIMENSIONS IN INCHES



AMPHENOL 7MM PRECISION CONNECTOR

AMPHENOL DWG NO. 693-158

The Badger design included a pair of prongs on each of the two coupling nuts of the connector. A helical radial surface on each of the prongs engaged a helical radial surface on the inside of its mating nut. Amphenol production of this coupling nut mechanism showed that it was extremely difficult to hold the ramps square to the center line of the connector. Whenever the ramps are not square to the center line, axial contact is not good when the connector halves are coupled together. Also, the Badger connector did not exhibit sufficient rigidity when subjected to the expected bending loads of normal usage. Because of these two considerations, Amphenol and Hewlett-Packard decided to eliminate the prongs.

After considering several possibilities, Amphenol concluded that a sliding sleeve approach was most likely to meet both electrical as well as mechanical requirements. A new design was developed which incorporated a tight fit between the inside of a sliding sleeve (on the connector half with the coupling nut retracted) and the outside of the barrel (on the half with extended coupling nut). This tight fit aligns the connector and provides rigidity. Also, the outside diameter on the new design is smaller than it was on the original. The final Amphenol product, a commercial success, is shown in Exhibit C2. Engineering drawings of the connector appear in Exhibits C3 and C4.

April 5, 1966 A. S. BADGER 3,245,028

CONNECTORS

Filed Feb. 17, 1964

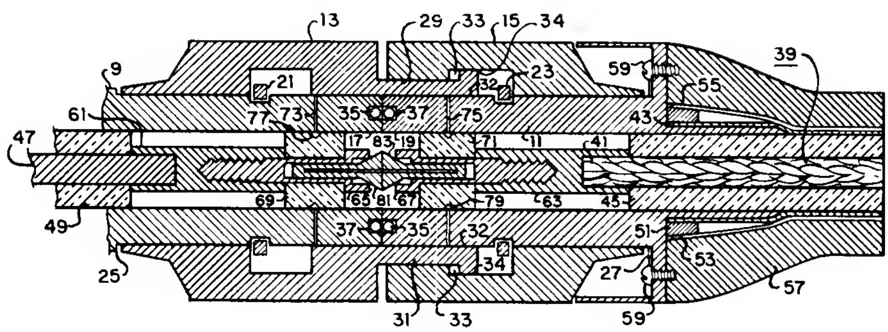


Figure 1

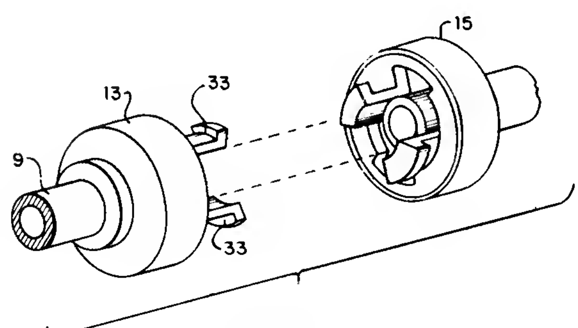


Figure 2

INVENTOR
ANTHONY S. BADGER
BY A. C. Smith
AGENT

Instructor's Note

ECL 1 was one of the first engineering cases prepared in an organized Stanford case program; it has also been one of the most frequently used. The original case was written in 1964. Later developments concerning the sexless connector were found to be of some instructional value, so that Part (C) was added three years later. This new section corrects the impression left by Part (B) that "only the marketing remained".

In the Stanford introductory design course, the case has provided exercises in conceptual design, sketching, and visual communication. For the design and sketching exercises, students would typically be given Part (A) and asked to organize a set of design criteria, then sketch a number of possible designs, describing advantages and disadvantages of each. Part (B), distributed in a later class, shows the actual connector designed by Tony Badger for comparison. The case has also provided a very challenging assignment in visual communication. Students have been asked to imagine they are in Mr. Badger's position, having designed a new product whose advantages must now be conveyed to management. The assignment has been to communicate graphically, on a single sheet suitable for use as a slide, how the new connector works. The slide will be shown for only a short time and should require no verbal accompaniment, so that clarity and simplicity are essential.

The case could also be used for dimensioning and tolerancing exercises; one assignment of this type could be to prepare detail drawings of several other parts using the last page of Exhibit B-9 as an example.

ECL 1 has also been useful as a discussion case. One subject raised by the case is the process of creative design, of which Tony Badger's procedure in Part (B) is one example. Tony's approach was learned under the late Professor John Arnold, a pioneer in developing the creative talent of his students. Tony's design steps give a fair idea of the Arnold method. This section of the case might provide instructors with a good opportunity to introduce ideation techniques, either in conjunction with the connector problem or an entirely new one.

After reading Part (B), students might be asked what they would have done differently, what problems they foresee with the connector, what additional tests they might carry out, etc. Because Mr. Badger alone has described the development of the connector, most students will probably say they see few problems, that Tony has a great design. They will be amazed to see later that Amphenol chose not to use his clever internal prong concept. After students have had a chance to read Part (C), the instructor might wish to emphasize several points:

1. The design engineer needs to know manufacturing. Tony Badger's twist-lock scheme was rejected at least partly because of a tolerance problem which would drive production costs too high. The bids included as Exhibit B-8 indicate that production costs were already well above Tony's estimates.

2. If you want to see your idea marketed, better follow it through yourself. None of the problems mentioned by Amphenol appears unsolvable; it seems more likely that the joining method was changed because Amphenol's engineers were working on a sliding sleeve scheme, with which they were more familiar than the pronged twist-connect concept. Tony, incidentally does not agree with some of the statements made in Part (C), pointing out that Hewlett-Packard has used a large number of the original connectors for several years without experiencing the kind of problems mentioned by Amphenol. If Hewlett-Packard had continued development of the connector, rather than selling to Amphenol, only minor changes might have been made in the design.

3. The value of an idea is often difficult to ascertain except in retrospect. Strangely, the feature of Mr. Badger's which was retained - the split collet - was almost an afterthought, yet it was really the only feature for which he was awarded a patent. The idea which Tony thought was the crux of his design - the prongs - was apparently not patentable except in conjunction with the expanding collet, and was later dropped.